J. H. Libbey

CHIMNEY DESIGN AND THEORY

A BOOK FOR

ENGINEERS AND ARCHITECTS

BY

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PREFACE

Up to the present time, there has been but one book on the subject of "Chimneys" printed in the United States, that of Armstrong's, revised by F. E. Idell, and published in the "Van Nostrand Science Series." It is a treatment of chimney-draft only. Other than this, the only book of any pretension is that of Bancroft's, an English book, published in 1885, and no longer obtainable. Thus it may be seen that there is no book which contains the latest practice in regard to the theory and designing of chimneys as built in the United States.

The Transactions of the engineering societies and volumes of technical periodicals do not give very much that is of value excepting, however, the "Engineering News" and "Engineering Record," to whom, with Mr. Henry C. Meyer, Jr., I am especially grateful for courtesies extended.

Whenever any extracts are made use of they are credited as far as possible to their source, and my thanks are tendered for the use of same, and to Mr. F. E. Idell for many valuable suggestions and criticisms.

The absence of data on this important subject has induced me to prepare this treatise, and if it meets with the same success that attended my pamphlet, "Chimney Formulæ and Tables," 1897, and will prove to be a source of information and assistance to designers, my object will be attained.

William Wallace Christie.

Paterson, N. J., May, 1899.

PREFACE TO THE SECOND EDITION

For a second edition the book has been revised throughout, some twenty-five pages of text and twelve full-page illustrations being added.

Radial brick chimneys, which were just being introduced in the United States as the first edition went to press, are now treated of briefly.

I have tried in a limited space to round out the work, thus meeting some of the criticisms made by the reviewers of the original publication, and I will be grateful for any suggestions that may be sent me looking to the further improvement of the work.

Mechanical draft is not enlarged upon, it being a subject by itself.

I desire to thank those who by their interest in the first edition have made this revision now possible.

WILLIAM WALLACE CHRISTIE.

March, 1902.

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CHAPTER I

INTRODUCTION AND HISTORY

INTRODUCTORY

THE most prominent feature to the world at large, of every steam or power plant, and that by which the manufacturing character of a village or city is most easily distinguished, is the chimney.

It is an engineering work which is often given but little thought, so far as the proper size and proportions for the best results are concerned, by those for whom it is to be built.

Nothing in a steam plant is so conducive to great waste of fuel as a badly designed chimney; and it may be made the means of assisting or increasing a high efficiency in the plant, if properly proportioned for the quantity of gases which is to be passed through it.

Chimneys are built of brick, or steel, or stone; steel chimneys being sometimes stayed or guyed with iron rods or wire rope, and sometimes built self-sustaining; in all cases chimneys are set on heavy masonry foundations.

In the following pages the adjuncts and various types of chimneys will be treated separately.

HISTORICAL NOTES.

According to Tomlinson, chimneys were probably in use in England before those of Padua, of which the earliest record is the year 1368, when Carrara, Lord of Padua, introduced them in Rome.

The use of the curfew-bell in preceding centuries indicates their absence, as the ringing of the bell was the signal to cover the fires (couvre-few), which were made in pits, for the night.

In Venice, chimneys were common in the fourteenth century, a number being overthrown by the earthquake of January 25, 1347.

Of the nations of antiquity little in this direction is known.

No traces of chimneys have been found in the ruins of Pompeii or Herculaneum.

Charcoal has been found, it being used, no doubt, in the portable furnaces discovered in the rooms.

Roman houses were frequently heated by means of hot air, which was brought in pipes from a furnace below.

In the dwellings of the Greeks there were no chimneys, the smoke escaping through a hole in the roof.

The Persians still retain their ancient custom of making fires in a hole in their earthen floors, in an iron vessel, and thus heat their apartments, which plan is said to give very satisfactory results. A low table is placed over the heater, with a thick quilted cloth reaching to the floor, and no provision is made for the escape of the products of combustion.

There is no evidence of chimney-shafts in England earlier than the twelfth century.

Leland, speaking of Bolton Castle, says, " . . . was fyniched or Kynge Richard the 2 dyed . . : one thynge I much notyed in the hawle of Bolton, how chimneys were conveyed by tunnells made in the syds of the walls betwixt the lights in the hawle, and by this means, and by no covers, is the smoke of the harthe in the hawle wonder strangely conveyed."

For centuries afterward chimneys remained luxuries for the houses of the great.

At the beginning of the sixteenth century, chimneys were almost unknown ; the fire was kindled against a hob of clay called the *rere dosse*, in the back or centre of the room, which was filled with smoke, from the wood (which was the only fuel used), that found its way out by an opening or lantern in the roof.

The houses built at Amboy, N. J., in 1683 are described usually thirty feet long, sixteen feet wide, ten feet between joints, with double chimneys of timber and clay, "as the manner of this country is to build," and cost about fifty pounds each ($250).

The chimney in its present sense of a funnel from the hearth or fireplace to the roof of the house, is a modern invention.

In 1785, Mr. Watt procured a patent for obviating the smoke of steam-engines by placing the coal in an upright conical tube or hopper fixed in the brickwork of the boiler, immediately behind the furnace door, and causing a stream of air to rush through the furnace door for maintaining combustion.

In Mr. John Bourne's "Treatise on the Steam-engine," p. 51, he shows a boiler and furnace designed by John Smith, of Kingston near Dublin, which has a vertical chimney, designed probably about 1825.

Rev. D. Lardner, "The Steam-engine," p. 128, speaks of the gases passing about the boiler and in immediate contact with it, and finally issuing into the chimney; but he says nothing about the design of the chimney.

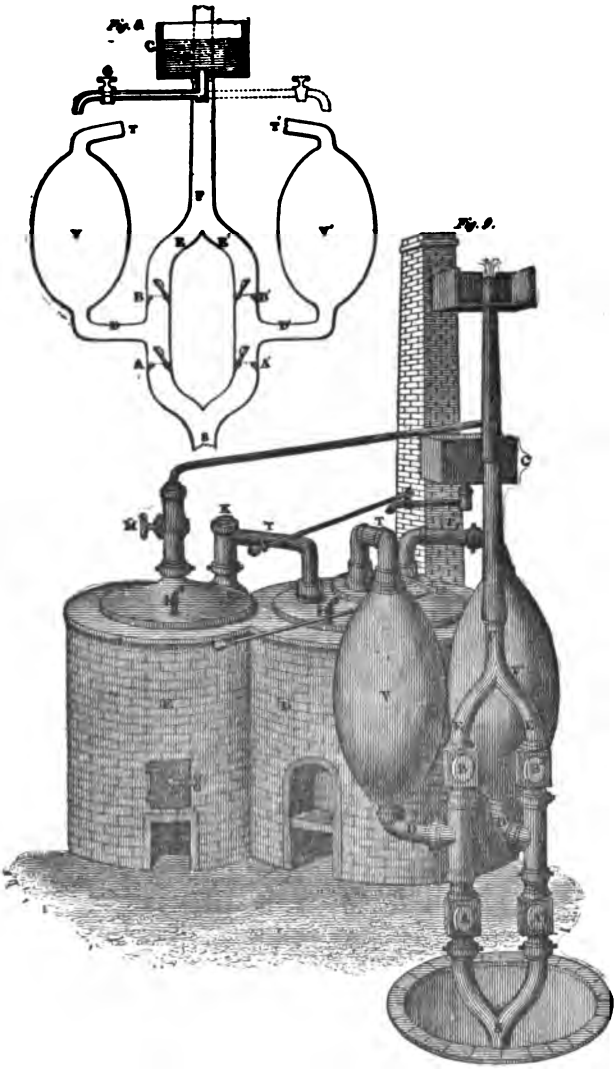
In the same book, in an illustration of Savery's steam-engine, 1702, a brick chimney is shown. This is also the first illustration in Dr. R. H. Thurston's "Growth of the Steam-engine," of a chimney-shaft in connection with a steam-boiler.

The following is abstracted from Bishop's "History of American Manufactures":

Gawen Lawrie, settler of East New Jersey in 1684, says "the country farm-houses they build very cheap, . . . the chimneys are stone." Bricks were used by some.—Volume I., page 226.

"Stone and bricks, of which last ten thousand were sent from London to Massachusetts in 1629, were first used in the construction of the fireplaces, which were usually of the most ample dimensions."—Volume II., page 219.

"In 1789 the first steam-engine for cotton spinning was



Engr. by P. Maverick.

ILLUS. No. 1.

SAVERY'S STEAM ENGINE AND BOILER, 1702.

From "The Steam Engine," by Rev. Dionysius Lardner, LL.D., F.R.S.

erected at Manchester, England." It must have been used with a boiler and chimney.—Volume II., page 19.

"Rooseveldt, in connection with James Sullivan, took out a U. S. Patent, May 31, 1798, for a double steam-engine, and soon after constructed probably the first effective steam-engine, after those of Fitch, ever built in America."—Volume II., page 80.

"He completed one in 1800, with a wooden boiler, through which long cylindrical flues, or heaters, wound several times before entering the chimney." It was for the use of the Philadelphia, Pa., Water-works.

A great many chimneys having but one thickness of brick, and the exterior bonded together with hoop-iron bands, were erected at the Potteries during the years 1847–1867 by Mr. Scrivenor, of Hawley, England.

CHAPTER II

THEORY OF CHIMNEY-DRAFT

FURNACE or chimney-draft is produced by one of the following methods:

I. By a natural draft due to the unbalanced pressure of a column of heated gases against a heavier column of outside air.

II. By the use of a steam-jet in the chimney, inducing draft, using either live or exhaust steam from the engine.

III. By a forced draft from a steam blower in the furnace of a boiler setting or a fan feeding through pipes to the furnace.

IV. By induced draft from blowers placed between boiler setting and chimney flue, blowers being usually placed at the base of the chimney.

What follows is abstracted from a paper by Professor De-Volson Wood, in the Transactions of the American Society of Mechanical Engineers, Vol. XI.

Peclet's and Rankine's hypotheses are:

1. A certain amount of air must pass through the grate and the body of the coal on the grate to secure combustion.

2. Since the openings for the admission of air are fixed mechanically the requisite amount of air must be supplied at a definite velocity.

3. The required velocity may be produced by the pressure of a column of atmospheric air, which pressure will be the difference of the pressure of the external air and that within the furnace. The height of such a column is called a "head."

4. That, to the head described in the preceding condition, a head must be added sufficient to overcome the resistance offered by the coal to the passage of the air through it; and

another head for the resistance offered by the flues and chimney to the passage of the gases produced by combustion.

The law representing these conditions is given in the form of an equation by Peclet thus:

$$(1)\quad h=\frac{u^2}{2g}\left(1+G+\frac{fl}{m}\right),$$

in which

u is the required velocity of gases *in the chimney*,
G, a constant to represent the resistance to the passage of air through the coal,
l, the length of the flues and chimney,
m, the mean hydraulic depth or the area of a cross-section divided by the perimeter,
f, a constant depending upon the nature of the surfaces over which the gases pass, whether smooth, or sooty and rough.

If now

A, be the section of the chimney in square feet,
H, the height of the chimney in feet,
$\tau_0 = 461°$ Fahr., absolute (temperature of melting ice),
τ_1, the temperature of the gases in the chimney, absolute,
V_0, the volume of air at the temperature 32° Fahr., supplied per pound of fuel burned on the grate,
w, the pounds of fuel burned *per second*,
n, the ratio of grate area to that of the chimney area,
S, the area of the grate;

then $$(2)\quad wV_0\frac{\tau_1}{\tau_0} = uA = nuS.$$

The pounds of coal or fuel burned per square foot of grate per hour will be

$$(3)\quad 3600\frac{w}{S} = 3600\frac{nu}{V_0}\cdot\frac{\tau_0}{\tau_1}.$$

Peclet found that when 20 to 24 pounds of coal is burned per hour, the value of G is about 12, and f, for sooty surfaces, equals 0.012.

Professor Wood has assumed 12 for G, except when 16 pounds is burned, when 11 is used.

Neglecting the length of the flue, let $f = 0.015$. Then for

square or round chimneys, in which b is the breadth or diameter, we have

$$(4)\quad h = \frac{V_0^2}{2g}\left(\frac{w}{A}\right)^2\left(\frac{\tau_1}{\tau_2}\right)^2\left(13 + \frac{0.060bH}{A}\right).$$

Rankine's determination of the height was for the purpose of deducing the head h. His hypotheses are:

1. The gases in the chimney are uniformly hot;
2. The gases move in parallel sections through the chimney;
3. The density of the gases in the chimney is uniform, and does not differ sensibly from that of air at the same temperature and pressure; in other words, it is assumed that the density varies with the temperature only, the variation of pressure being neglected in determining the density.
4. "The head producing the draft in the chimney is equivalent to the excess of the weight of a vertical column of cool air outside the chimney, and of the same height, above that of a vertical column of equal base of the hot gases within the chimney."
5. That the draft is a maximum when the *weight* of gases discharged is the greatest.

The fourth hypothesis is improperly defined, since the head is defined as a weight, whereas it is a height in feet. Professor Wood defines it as such a height of hot gases as, if added to the column of gases in the chimney, would produce the same pressure at the furnace as a column of outside air, of the same area of base, and a height equal to that of the chimney.

If 24 pounds of air be supplied per pound of fuel the volume of the gaseous product will be $24 \times 12\frac{1}{2} = 300$ cubic feet (nearly), and one cubic foot will weigh $\frac{1}{300} = 0.0033$ of a pound at 32° Fahr., which, added to the weight of a cubic foot of air at 32° Fahr., gives $0.0807 + 0.0033 = 0.084$ of a pound; and if τ_2 be the temperature of the external air, we have at once from the fourth principle as amended,

$$(5)\quad h = \frac{\frac{\tau_0}{\tau_2}(0.0807)}{\frac{\tau_0}{\tau_1}(0.084)}H - H = \left(0.96\frac{\tau_1}{\tau_2} - 1\right)H;$$

which is the formula given by Rankine. From this we find

$$(6)\quad H=\frac{13\frac{V_0^2}{2g}\left(\frac{w}{n\delta}\right)^2\left(\frac{\tau_1}{\tau_0}\right)^2}{0.96\frac{\tau_1}{\tau_2}-1-\frac{0.06b}{2gA}\left(V_0^2\frac{w}{n\delta}\frac{\tau_1}{\tau_0}\right)^2}.$$

This gives the height of chimney for burning w pounds of coal per second.

If δ be the weight of a cubic foot of the gases in the chimney, and

N, the number of pounds of air required per pound of coal (about 24 pounds), then will the weight of gases passed up the chimney be

$$(7)\quad \begin{aligned} 2\delta V_0\frac{\tau_1}{\tau_0}\delta &= 0.0807Nw \text{ nearly};\\ \therefore \delta &= \frac{0.0807N\tau_0}{V_0\tau_1}. \end{aligned}$$

The weight per second will also be δ times the volume, or $Au\delta$; hence

$$(8)\quad Au\delta=\frac{0.0807N\tau_0 A\sqrt{2gH}\sqrt{0.96\frac{\tau_1}{\tau_2}-1}}{V_0\tau_1\left(1+G+\frac{0.06bH}{A}\right)}.$$

Observing that $N\div V_0$ will be constant, this expression will be a maximum for a given chimney when the function

$$(9)\quad \frac{\sqrt{0.96\frac{\tau}{\tau_2}-1}}{\tau\left(1+G+\frac{0.06bH}{A}\right)}$$

is a maximum. If G be a variable, the maximum cannot be found unless it be a known function of the temperature. Little, however, is known of its value in special cases, and the law of variation cannot be assigned. If it be considered constant, as in the assumptions of Peclet and Rankine, the function for a maximum reduces to

$$\frac{0.96\tau-\tau_2}{\tau_2},$$

which is the function considered by Rankine, and gives

$\tau = 2\frac{1}{3}\tau_1$, a maximum; and if the temperature of the external air be 60°, then will the temperature of the gases be 622°.

From the foregoing rules Professor Wood has calculated the following table:

TABLE No. 1.

SHOWING THE HEIGHTS OF CHIMNEY AND CORRESPONDING HEADS FOR BURNING GIVEN AMOUNTS OF COAL.

τ_2	τ_1 Absolute.	24 lbs. coal per sq. ft. grate area.		20 lbs. coal per sq. ft. grate area.		16 lbs. coal per sq. ft. grate area.	
		Head, h ft.	Height, H ft.	Head, h ft.	Height, H ft.	Head, h ft.	Height, H ft.
520°	600	128.001	1207.57	52.76	497.73	14.02	132.33
Absolute	700	73.75	250.87	45.70	157.61	19.65	67.76
or	800	82.76	172.42	55.58	115.80	26.71	55.66
59° Fahr.	1000	125.22	149.08	83.97	99.97	40.89	48.68
	1100	153.22	148.76	101.87	98.91	49.61	48.17
	1200	182.34	151.97	121.03	100.86	58.87	49.06
	1400	252.51	159.86	161.92	105.65	80.89	51.20
	1600	334.38	168.83	219.68	110.95	105.96	53.52
	2000	555.53	206.52	355.61	132.20	169.47	63.007

It will be seen that the required heads equal the height of the chimney when the temperature in the chimney-flue is about 620° Fahr., the external air being assumed to be 60° Fahr.

The many different conditions found in the United States, and the complexity of the above equations, prevent their use to any great extent.

Those who wish to investigate more thoroughly the theory of chimney-draft will find material in the Trans. A. S. M. E., Vol. XI.

D. K. Clark deduces the following formula for force of draft in inches of water:

$$(10) \quad w = H\left(.0146 - \frac{7.66}{T'}\right).$$

w = force of draft in inches of water.
H = height of chimney in feet.
T' = absolute temperature, Fahr., of hot gases in chimney.
If $H = 135$ feet, and $T' = 550° + 461° = 1011°$ then,

$$(11) \quad w = 135\left(.0146 - \frac{7.66}{1011}\right) = 0.945 \text{ inch.}$$

Force of Intensity of Draft.—In this particular case 0.88 inch draft has been observed. The force of the draft is equal to the difference between the weight of the column of hot gases inside of the chimney and the weight of a column of the external air of the same height. It is measured by a draft-gauge, usually a U-tube partly filled with water, one leg connected by a pipe to the interior of the flue, and the other open to the external air.

If D is the density of air outside, d the density of the hot gas inside, in pounds per cubic foot, H the height of the chimney in feet, and .192 the factor for converting pressure in pounds per square foot into inches of water column, then the formula for the force of draft expressed in inches of water is

$$(12) \quad F = .192H(D - d).$$

The density varies with the absolute temperature (see Rankine),

$$(13) \quad d = \frac{\tau_0}{\tau_1} 0.085; \text{ see foot-note.}$$

$$(14) \quad D = 0.0807 \frac{\tau_0}{\tau_2};$$

where τ_0 is the absolute temperature at 32° Fahr., $\doteq$ 493°, τ_1 the absolute temperature of the chimney gases, and τ_2 that of the external air.

F. R. Low, in *Power*, February, 1900, says: The weight per cubic foot of chimney gas will vary with its composition.

Carbon dioxide is heavier than air, nitrogen and aqueous vapor is lighter; so it is easily seen that the density of the gases will depend upon the proportion of carbon and hydrogen which is being burned and with the excess of air used. For ordinary fuel and 19 pounds of air to one of combustible (20 pounds of gas) the gas will weigh .085 * pounds per cubic foot at 32° Fahr.

Substituting 13 and 14 in equation 12 the formula for force of draft becomes

$$(15) \quad F = .192H\left(\frac{39.79}{\tau_2} - \frac{41.41}{\tau_1}\right) = H\left(\frac{7.64}{\tau_2} - \frac{7.95}{\tau_1}\right),$$

or knowing the force of draft in inches of water it becomes, for obtaining the height of a chimney,

* Rankine, "Steam Engine," gives this decimal as varying from 0.084 to 0.087.

$$(15\text{ A.})\quad H=\frac{F}{\frac{7.64}{T_2}-\frac{7.95}{T_1}}$$

To find the maximum intensity of draft for any given chimney, the heated column being at 600° Fahr., and the external air at 60° Fahr., multiply the height above grate in feet by .0073, and the product is the draft in inches of water.

TABLE No. 1a. DENSITY OR WEIGHT PER CUBIC FOOT OF AIR, BY FORMULA 14.

TABLE No. 1b. DENSITY OR WEIGHT PER CUBIC FOOT OF CHIMNEY GAS, BY FORMULA 13.

Table 1a		Table 1b					
t	*D*	*t*	*d*	*t*	*d*	*t*	*d*
0	.086355	200	.063335	430	.046952	660	.037302
5	.085424	210	.062389	440	.046429	670	.036972
10	.084514	220	.061470	450	.045919	680	.036647
15	.083623	230	.060578	460	.045419	690	.036328
20	.082750	240	.059711	470	.044930	700	.036015
25	.081895	250	.058869	480	044451	710	.035707
30	.081058	260	.058051	490	.043983	720	.035404
32	.080728	270	.057255	500	.043525	730	.035106
35	.080238	280	.056480	510	.043076	740	.034814
40	.079434	290	.055726	520	.042636	750	.034526
45	.078646	300	.054992	530	.042205	760	.034242
50	.077874	310	.054277	540	.041782	770	.033964
55	.077117	320	.053580	550	.041368	780	.033690
60	.076374	330	.052901	560	.040962	790	.033420
65	.075645	340	.052239	570	.040564	800	.033155
70	.074930	350	.051594	580	.040174	900	.030715
75	.074229	360	.050964	590	.039791	1000	.028610
80	.073541	370	.050349	600	.039415	1100	.026775
85	.072865	380	.049750	610	.039047	1200	.025161
90	.072201	390	.049163	620	.038685	1300	.023731
95	.071550	400	.048591	630	.038330	1400	.022455
100	.070910	410	.048032	640	.037981	1500	.021308
		420	.047486	650	.037639	1800	.018479
						2000	.016976

—F. R. Low, *Power*, 1900.

The readings of all draft-gauges will vary somewhat from the figures in Table No. 2, as the same condition of variation in temperature from bottom to top exists to a greater or less extent in all chimneys.

For any other height of chimney than 100 feet, the height of water-column is found by simple proportion, the height of the water column being directly proportional to the height of the chimney.

The calculations have been made for a chimney 100 feet

high, with various temperatures outside and inside of the flue, and on the supposition that the temperature of the chimney is uniform from top to bottom.

TABLE No. 2.

HEIGHT OF WATER-COLUMN DUE TO UNBALANCED PRESSURE IN CHIMNEY 100 FEET HIGH.

Temperature in the chimney.	Temperature of external air.—Barometer 14.7.										
	0	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
210	.470	.436	.401	.371	.338	.309	.280	.251	.227	.200	.175
220	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
230	.505	.470	.436	.405	.372	.344	.315	.286	.261	.234	.209
240	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
250	.537	.503	.468	.438	.405	.376	.347	.319	.294	.267	.242
260	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
270	.568	.534	.499	.468	.436	.407	.378	.349	.324	.298	.273
280	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
290	.597	.563	.528	.497	.465	.436	.407	.379	.353	.326	.301
300	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
310	.624	.589	.555	.524	.492	.463	.434	.405	.380	.353	.328
320	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
330	.651	.616	.582	.551	.518	.489	.461	.432	.407	.380	.355
340	.662	.628	.593	.563	.530	.501	.472	.443	.419	.392	.367
350	.676	.641	.607	.576	.543	.514	.486	.457	.432	.405	.380
360	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
370	.699	.664	.630	.599	.566	.538	.509	.480	.455	.428	.403
380	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
390	.722	.687	.652	.622	.589	.561	.532	.503	.478	.451	.426
400	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
410	.743	.708	.674	.643	.610	.583	.553	.524	.499	.472	.447
420	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
430	.764	.730	.695	.664	.632	.602	.574	.545	.520	.493	.468
440	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
450	.783	.749	.714	.684	.651	.622	.593	.564	.540	.513	.488
460	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
470	.802	.768	.733	.703	.670	.641	.612	.584	.559	.532	.507
480	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
490	.820	.785	.751	.720	.687	.659	.630	.601	.576	.549	.524
500	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

This is the basis on which all calculations respecting the draft-power of chimneys have been made by Rankine and others, but it is very far from the truth in most cases.

The difference will be shown by comparing the reading of the draft-gauge with the table given. In one case a chimney 122 feet high showed a flue temperature at the base of 320° Fahr., and at the top 230° Fahr., while the table considers the temperature uniform.

Box gives this table: internal air at 552° Fahr., external air at 62° Fahr.; damper nearly closed.

TABLE No. 3.

DRAFT-POWERS OF CHIMNEYS.

Height of chimney—feet.	Draft in inches of water.	Theoretical velocity—feet per second.	
		Cold air entering.	Hot air at exit.
10	.073	17.8	35.6
20	.146	25.3	50.6
30	.219	31.0	62.0
40	.292	35.7	71.4
50	.365	40.0	80.0
60	.438	43.8	87.6
70	.511	47.3	94.6
80	.585	50.6	101.2
90	.657	53.7	107.4
100	.730	56.5	113.0
120	.876	62.0	124.0
150	1.095	69.3	138.6
175	1.277	74.3	148.6
200	1.460	80.0	160.0

TABLE No. 4.

VOLUME, DENSITY, AND PRESSURE OF AIR AT VARIOUS TEMPERATURES.

Fahr.	Volume at atmos. pressure.		Density lbs. per cubic foot at atmos. pressure.	Pressure at constant volume.	
	Cubic ft. in 1 lb.	Comparative volume.		Lbs. per sq. in.	Comparative pressure.
0	11.583	.881	.086331	12.96	.881
32	12.387	.943	.080728	13.86	.943
40	12.586	.958	.079439	14.08	.958
50	12.840	.977	.077884	14.36	.977
62	13.141	1.000	.076097	14.70	1.000
70	13.342	1.015	.074950	14.92	1.015
80	13.593	1.034	.073565	15.21	1.034
90	13.845	1.054	.072230	15.49	1.054
100	14.096	1.073	.070942	15.77	1.073
110	14.344	1.092	.069721	16.05	1.092
120	14.592	1.111	.068500	16.33	1.111
130	14.846	1.130	.067361	16.61	1.130
140	15.100	1.149	.066221	16.89	1.149
150	15.351	1.168	.065155	17.19	1.168
160	15.603	1.187	.064088	17.50	1.187
170	15.854	1.206	.063089	17.76	1.206
180	16.106	1.226	.062090	18.02	1.226
200	16.606	1.264	.060210	18.58	1.264
210	16.860	1.283	.059313	18.86	1.283
212	16.910	1.287	.059135	18.92	1.287

Widening the Top of Chimney Flue.—The effect of widening the chimney flue at the top or mouth is, according to Dubois-Weisbach, as follows: strictly speaking, according to the principles of hydraulics (Vol. I., § 425), in the formula $Q = 0.47S\sqrt{\frac{(t_1 - t)hd}{30d + 0.05h}}$ we should insert for S not the mean cross-section, but that at the mouth, hence, other things being equal, a chimney which gradually widens toward the mouth or top can discharge more gas and smoke than one which diminishes.

Q = cubic feet of gas per second.
d = diameter, in feet.
h = height in feet.
t = temperature of outer air.
t_1 = temperature of escaping gases in the flue.

From Weisbach, we find that Q is a maximum when $t_1 - t = 273°$ Cent., and we have $v = 1.32\sqrt{h}$ in feet; $S = \frac{0.76Q}{\sqrt{h}}$ in feet. If outer temperature is 32° Fahr. then gases are 555° Fahr.

Except in cases where the gases have a very high velocity, as in the locomotive chimney, the writer fails to find any advantage in widening the mouth of chimneys; in locomotive practice it has been proven, however, that the taper stack with diverging sides is the most efficient type.

Illustration No. 35 is of a chimney whose flue widens toward the top or mouth.

Pyrometers.—The high temperatures and peculiar currents of gases in the chimney make it very difficult to ascertain definitely what the temperature is. The clock-face pyrometers made for general use, and whose indications depend on the unequal expansions of metals in their stem, are not considered very reliable, particularly as the zero point is subject to change during the handling of the instrument.

The most satisfactory type of pyrometer is that in which a thermo-electric couple is made use of, but this type has not come into general use; the metal pyrometers just described being considered sufficiently accurate for commercial purposes.

CHAPTER III

CHIMNEY FORMULÆ

PROFESSOR H. B. GALE gives this handy rule, that the sectional area of the chimney in square feet should be equal to the number of pounds of fuel to be burned per minute. This would make the velocity of chimney gases betwcen 7 and 11 feet per second.*

Mr. Gale also suggests the following rules:

(17) Flue area in square feet $= A = .07\ F^{\frac{1}{2}}$

(18) Height of chimney in feet $= H = 100 \frac{K}{t}\left(\frac{F}{A}\right)^2$

where a may be considered $\frac{1}{3}$ of grate area in square feet.

K may be approximately taken as 0.2.

$F =$ pounds of fuel burned per hour.

$G =$ grate area in square feet $= 3a$.

$t =$ temperature of chimney gases.

$$(19)\quad H = \frac{180}{t}\left(\frac{F}{G}\right)^2;$$

$$(20)\quad F = \frac{a}{10}\sqrt{\frac{Ht}{K}};$$

$$(21)\quad a = 10F\sqrt{\frac{K}{Ht}};$$

which enables us to calculate the openings in the grate for the admission of air.

Professor Gale has calculated Table No. 5, the temperature of gases in a chimney being taken as 500° Fahr. The heights obtained by calculation are said to agree fairly well with American practice.

* Only for chimneys of small dimensions.

TABLE No. 5.

GALE'S CHIMNEY TABLE.

H. P.	Coal per hour, F.	Coal per sq. ft. grate, R.	Area grate, G. $\left(=\frac{F}{R}\right)$	Area opening, a. $(=0.4\ G.)$	Height, $H=100\frac{K}{t}\left(\frac{F}{a}\right)^2$
	lbs.	lbs.	sq. ft.	sq. ft.	ft.
20	100	13	7.7	3	44
60	300	15	20	8	56
100	500	17	30	12	70
200	1000	19	53	21	90
400	2000	21	95	38	111
600	3000	23	130	52	133
1000	5000	25	200	80	156

Chimney Rules.

Adams gives:

Chimney for one boiler: area = $\frac{1}{8}$ of fire-grate.

Chimney under 150 feet high for more than one boiler: area = $\frac{1}{10}$ fire-grate area.

Chimney over 150 feet high for more than one boiler: area = $\frac{1}{15}$ fire-grate area.

Rankine gives, "Rules and Tables," p. 29:

Area of grate = .10 to .04 square feet per pound of fuel burned per hour.

Area of grate in furnaces with forced draft by blast-pipe from .04 to .01 square foot per pound of fuel burned per hour.

Area of chimney = .10 area of grate.

D. K. Clark, "Thurston's Manual of Steam-engineering," Vol. II., p. 201:

Sectional area of tubes, inside = $\frac{1}{8}$ grate surface.

Sectional area of chimney = $\frac{1}{15}$ grate surface.

Sectional area blast orifices = $\frac{1}{65}$ grate surface.

Height of chimney in feet = its diameter in inches multiplied by 4.

Transactions of the "American Society of Mechanical Engineers," Vol. XV., p. 607, gives:

$$A = \frac{C}{12\sqrt{H}} \div 1.076.$$

1.076 is constant for a horizontal flue 50 feet long.

Nystrom gives:

$$H = \frac{C^2}{4G^2} - 2 \qquad A = \frac{HP}{1.45\sqrt{H}}$$

$$H = \frac{(HP^2)}{2.1A^2} \qquad G = \frac{C}{2\sqrt{H+2}}$$

$$C = 2G\sqrt{H+2}$$

Jones and Laughlin give:

$$A = \frac{C}{10\sqrt{H}} \qquad A = \frac{1.04HP}{\sqrt{H}}$$

Another formula is

$$HP = \sqrt{S \times G}$$

$$S = \frac{(HP)^2}{G} \qquad G = \frac{(HP)^2}{S}$$

Molesworth gives:

$$A = \frac{HP}{1.28\sqrt{H}} \qquad A = \frac{C}{12\sqrt{H}}$$

Adams, p. 155, "Hand-book for Mechanical Engineers," gives:

$$A = \frac{C}{14\sqrt{H}} \qquad H = \left(\frac{C}{14A}\right)^2$$

$$C = 14A\sqrt{H}.$$

G = square feet of grate surface.
S = square yards of heating surface.
C = pounds coal per hour.
H = height of chimney in feet.
A = area of chimney-flue in square feet.
HP = horse-power of boilers.

William Kent gives the following, assuming a commercial horse-power to demand the consumption of 5 pounds of coal per hour:

Let A = actual section of chimney-flue in square feet.
Let HP = boiler horse-power.

(22) $E = \frac{0.3HP}{\sqrt{H}} = A - 0.6\sqrt{A}$ = effective section in square feet.

(23) $HP = 3.33E\sqrt{H}$ = horse-power.

(24) $d = 13.54\sqrt{E} + 4''$ = diameter of round flue in inches

(25) $S = 12\sqrt{E} + 4''$ = side of square flue in inches.

(26) $H = \left(\frac{0.3HP}{E}\right)^2$ = height of chimney in feet.

After numerous examples and discussion, D. K. Clark, in Vol. I. of "The Steam-engine," constructs the following formulæ:

Working maximum consumption of coal per hour, for a chimney of a given height: diameter at the top, one-thirtieth of the height; temperature in the flue, 600° Fahr.

$$(27) \quad C = .014H^2\sqrt{H}.$$

C = coal consumed per hour in pounds.
H = height of chimney in feet.
G = area of grate in square feet.

Taking as an average rate of combustion 15 pounds of coal per square foot of grate per hour, we have: Total grate area for a chimney of a given height; conditions as above:

$$(28) \quad G = \frac{H^2\sqrt{H}}{1071} \text{ or: } H = 16.3\sqrt[2.5]{G}.$$

Another formula has been quite widely published, which applies to about the same conditions as were assumed by Mr. Kent, and agreeing well with Isherwood's experiments on anthracite coal is given by Dr. R. H. Thurston. Subtract one from twice the square root of the height, and the result is the rate of combustion for anthracite. For low-grade soft coals the result is to be multiplied by 1.5—for general use we may use the mean of the figures for best anthracite and low-grade bituminous coal, or a multiplier of 1.25. Mr. Nagle * examined a good many chimneys, varying from 300 to 1,000 horse-power, to see if there existed any common ratio between these two elements. Where a smaller ratio than 1½ square inches of area to 1 pound of coal burned per hour existed, much dissatisfaction existed as to the draft of the chimney; when it reached 2 square inches very satisfactory results were obtained.

* Transactions of the American Society of Mechanical Engineers.

CHAPTER IV

CHIMNEY TABLES, WIND-PRESSURE, AIR-SPACE IN GRATES

RATE OF COMBUSTION

THE results of 45 tests of boilers with anthracite and Welsh steam coal give only 5 instances where the rate of combustion was greater than 13 pounds of coal per square foot of grate per hour, and all of the tests showed the rate of evaporation from and at 212° Fahr. per pound of combustible to be 8.11 pounds to 14.23 pounds.

The same quantity of coal as used in the above tests, burned on a smaller grate, evaporated more water per pound.

Averages of 15 tests by Isherwood give the following data:

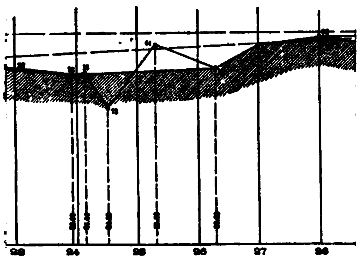
	Coal per sq. ft. of grate per hour.	Evaporation from and at 212° F. per lb. coal.
Anthracite coal	12.75	8.90
Semi-bituminous coal	10.95	10.14
Bituminous coal	12.43	9.31

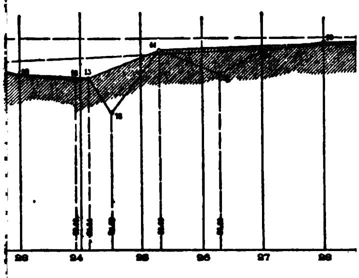
Another case—Average of 15 boilers tested gives 13.87 pounds of coal to square foot of grate per hour, while only 7 tests exceed 13 pounds (capacity trials).

For economy trials we have the average of 15 tests, giving 9.77 pounds of coal per square foot of grate per hour; none being over 13 pounds.—Clark, Volume I.

Thurston—"Steam Engine and Boiler Trials," p. 17, says the "efficiency of fuel falls off at 50 to 60 pounds of fuel burned per square foot of grate" (per hour).

In the plotted tests of the writer, PLATE I, all regularity ceases after 37 pounds of coal burned per square foot of grate is reached.





The following averages are from over 100 tests collated by the writer:

Pounds of coal per horse-power developed per hour.......	3.64
Pounds of combustible per horse-power developed per hour	3.04
Pounds of coal burned per square foot of grate per hour..	18.16

Professor Rankine says: "The rate of combustion in factory boilers is 12 to 16 pounds of coal to the square foot of grate."

Dr. Thurston says, in "Steam Engine and Boiler Trials": "In land boilers it is customary to keep the rate of combustion per square foot of grate down to about 8 pounds per hour, although it frequently rises to 10 or 12 pounds."

The preceding diagram shows that 13 pounds of coal burned per square foot of grate per hour of either anthracite or bituminous coal gives the greatest economy in evaporation.

The greatest amount of anthracite coal found to have been burned per square foot of grate per hour was 33.70 pounds; the least, 4.70 pounds.

The greatest amount of bituminous coal found to have been burned per square foot of grate per hour was 57 pounds; the least, 6.70 pounds.

Land stationary boilers are the only ones considered in these statements.

A noticeable feature of the plotted data is that the most economical boiler performances are obtained when a mixture of one part soft coal to two parts anthracite dust is burned at quite a high rate of combustion, forced draught being used.

The writer's object in giving "combustible" per square foot of grate is that the rating by combustible is the best way of comparing the tests of a number of boilers under which different coals are burned, and is a more reasonable criterion than that of coal only.

It will be readily seen from the averages that less than 4 pounds of coal in the majority of cases is that which is required to be burned per hour to produce one horse-power; and as 13 pounds of coal burned per square foot of grate is a most economical rate of combustion, 13 divided by 4, or 3.25 horse-power per square foot of grate per hour, is most economically attainable.

The above is for anthracite coal. For bituminous coal, as 23.8 pounds burned per square foot of grate is an economical rate of combustion, 23.8 divided by 4, or 5.95 horse-power per square foot of grate per hour, is economically attainable.

The average of 13 and 23.8 is 18.4, which is very nearly 18.16, the average of all the 108 tests; which confirms the correctness of common practice, as to rates of combustion.

CHIMNEYS.

The writer has found that a relation exists between the coal burned per square foot of grate, with efficient chimney draft, for anthracite and bituminous coal, and by assuming that

$$\text{coefficient} \times A \sqrt{H} = \text{coal per hour in pounds},$$

then $\text{coefficient} \times A \sqrt{H} = G \times$ coal per square foot of grate per hour, we find that for anthracite coal the coefficient equals the coal burned per square foot of grate, and that for bituminous coal the coefficient equals the coal burned per square foot of grate divided by 1.83.

The following tables, figured by formulæ given, will give satisfactory results to any who may use them; should any special modification be needed, the user must use his own judgment with regard to them.

Table No. 6. Grate area for a rate of combustion of 13 pounds per square foot of grate per hour.

Table No. 7. Grate area for a rate of combustion of 23.8 pounds per square foot of grate per hour.

Table No. 8. Coal capacity of chimney.

Table No. 9. Horse-power of boilers.

Table No. 10. Horse-power of chimneys, when two pounds of coal per hour burned furnishes one indicated horse-power at engine. Should the engine horse-power be known, and the chimney size wanted, great care should be exercised in determining it.

The last table is intended only for the one case. The writer has put himself on record as being decidedly in favor of rating chimneys at their coal capacity and not by horse-power.

The 23.8 is a derived constant obtained by multiplying 13 × 1.83; 1.83 confirms Mr. Harris's rule for grate area for bituminous coal burned with natural draft, 23.8 is an economical rate of combustion for bituminous coal.

A horse-power is understood throughout these tables to be the American Society of Mechanical Engineers' standard of 34½ pounds of water evaporated per hour from and at 212° Fahr.

TABLE No. 6.

DIAM.	AREA (A)	HEIGHT OF CHIMNEY														EQUIV.
		50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	Sq. Chim.
Inches.	Sq. Ft.	Grate Area $(G) = A\sqrt{H}$ for a rate of combustion of 13 lbs.														Side of Sq.
18	1.77	13	14	15	16											16″
21	2.41	17	19	20	21											19
24	3.14	22	24	26	28	30										22
27	3.98	28	31	33	35	38										24
30	4.91	35	38	41	44	47	49									27
33	5.94		46	50	53	56	59	62								30
36	7.07		55	59	63	67	70	74	79							32
39	8.30			69	74	79	83	87	93							35
42	9.62			81	86	91	96	102	108	120						38
48	12.57				112	119	126	132	141	157						43
54	15.90					151	159	167	178	199	210					48
60	19.64					186	196	206	220	246	260					54
66	23.76						238	249	266	297	314	336				59
72	28.27						283	296	317	353	374	400	424			64
78	33.13							348	371	415	449	469	498	525		70
84	38.48							403	431	481	509	544	577	608	666	75
90	44.18								495	552	584	625	663	698	765	80
96	50.27								563	628	665	711	754	795	871	86
102	56.75								636	709	749	802	851	897	983	91
108	63.62								712	795	841	900	954	1006	1101	96
114	70.88									886	937	1002	1063	1121	1228	101
120	78.54									982	1038	1111	1178	1242	1360	107
132	95.03									1188	1256	1344	1425	1502	1646	117
144	113.10									1414	1495	1630	1697	1788	1959	128

TABLE No. 7.

DIAM. Inches.	AREA (A) Sq. Ft.	HEIGHT OF CHIMNEY. 50′	60′	70′	80	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	EQUIV. Sq. Chim. Side of Sq.
		Grate Area (G) = $A\sqrt{H} \div 1.83$ for a rate of combustion of 23.8 lbs.														
18	1.77	7	7.8	8.1	8.7											16″
21	2.41	9	10	11	12											19
24	3.14	12	13	14	15	16										22
27	3.98	15	17	18	19	21										24
30	4.91	19	21	23	24	26	27									27
33	5.94		25	27	29	30	32	34								30
36	7.07		30	32	34	36	39	40	43							32
39	8.30			38	40	43	45	47	51							35
42	9.62			44	47	50	53	56	59	66						38
48	12.57				60	65	69	72	77	86						43
54	15.90					83	87	91	97	109	115					48
60	19.64					102	107	113	120	134	142					54
66	23.76						130	136	145	162	172	184				59
72	28.27						155	162	173	193	204	219	232			64
78	33.18							190	203	227	245	256	272	297		70
84	38.48							220	236	263	278	297	315	332	364	75
90	44.18								270	302	319	341	362	381	472	80
96	50.27								303	343	363	389	412	434	476	86
102	56.75								347	388	410	439	465	490	537	91
108	63.62								389	434	459	492	521	550	602	96
114	70.88									484	512	548	581	612	671	101
120	78.54									536	567	607	647	679	743	107
132	95.03									650	686	735	778	831	899	117
144	113.10									772	817	674	927	977	1070	128

TABLE No. 8.

DIAM. Inches.	AREA (A) Sq. Ft.	HEIGHT OF CHIMNEY. 50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	226′	250′	300′	EQUIV. Sq. Chim. Side of Sq.
		Horse Power = $3.25\ A\sqrt{H}$; 4 lbs. of coal burned considered 1 H. P.														
18	1.77	42	46	49	52											18″
21	2.41	55	62	65	68											19
24	3.14	72	78	85	91	98										22
27	3.98	91	101	107	114	124										24
30	4.91	114	124	133	143	153	159									27
33	5.94		149	163	172	182	192	202								30
36	7.07		179	192	205	218	228	241	257							32
39	8.30			224	241	257	270	283	302							35
42	9.62			263	282	296	312	332	351	390						38
48	12.57				364	387	410	429	458	510						43
54	15.90					491	517	543	579	647	683					48
60	19.64					605	637	669	715	797	845					54
66	23.76						774	809	865	965	1021	1092				59
72	28.27						920	962	1051	1147	1215	1300	1378			64
78	33.18							1131	1206	1349	1459	1624	1619	1706		70
84	38.48							1310	1401	1563	1654	1768	1875	1976	2165	75
90	44.18								1609	1794	1898	2031	2155	2269	2486	80
96	50.27								1830	2041	2161	2311	2451	2584	2831	86
102	56.75								2067	2304	2434	2607	2766	2915	3195	91
108	63.62								2314	2584	2734	2925	3101	3269	3578	96
114	70.88									2679	3045	3257	3455	3643	3991	101
120	78.54									3191	3374	3611	3829	4037	4420	107
132	95.03									3861	4082	4368	4631	4882	5350	117
144	113.10									4596	4859	5200	5515	5811	6367	128

TABLE No. 9.

DIAM. Inches.	AREA (A) Sq. Ft.	HEIGHT OF CHIMNEY. 50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	EQUIV. Sq. Chim. Side of Sq.
		Horse Power = 6.5 A√H. When 2 lbs. coal burned per hour = 1 H. P.														
18	1.77	84	92	98	104											16″
21	2.41	110	124	130	136											19
24	3.14	144	156	170	182	196										22
27	3.98	182	202	214	228	248										24
30	4.91	228	248	266	286	306	318									27
33	5.94		298	326	344	364	384	404								30
36	7.07		358	384	410	436	456	482	514							32
39	8.30			448	482	514	540	566	604							35
42	9.62			526	564	592	624	662	702	780						38
48	12.57				728	774	820	858	916	1020						43
54	15.90					982	1034	1086	1158	1294	1366					48
60	19.64					1210	1274	1338	1480	1594	1690					54
66	23.76						1548	1618	1730	1930	2042	2184				59
72	28.27						1840	1924	2102	2294	2430	2600	2756			64
78	33.18							2262	2412	2698	2918	3048	3238	3412		70
84	38.48							2620	2802	3126	3308	3536	3750	3952	4330	75
90	44.18								3218	3588	3796	4062	4310	4538	4972	80
96	50.27								3660	4082	4322	4622	4902	5168	5662	86
102	56.75								4134	4608	4868	5214	5532	5830	6390	91
108	63.62								4628	5168	5468	5850	6202	6538	7156	96
114	70.88									5758	6090	6514	6910	7286	7982	101
120	78.54									6382	6748	7222	7658	8074	8840	107
132	95.08									7722	8164	8736	9262	9764	10700	117
144	113.10									9192	9718	10400	11030	11622	12734	128

TABLE No. 10.

DIAM. Inches.	AREA (A) Sq. Ft.	HEIGHT OF CHIMNEY. 50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	EQUIV. Sq. Chim. Side of Sq.
		Pounds of coal burned per Hour. = 13 x G.														
18	1.77	169	182	195	208											16″
21	2.41	221	247	260	273											19
24	3.14	286	312	338	364	390										22
27	3.98	364	403	429	455	494										24
30	4.91	455	494	533	572	611	637									27
33	5.94		598	650	689	728	767	806								30
36	7.07		715	767	819	871	910	962	1027							32
39	8.30			897	962	1027	1079	1131	1209							35
42	9.62			1053	1128	1183	1248	1326	1404	1560						38
48	12.57				1456	1547	1638	1716	1833	2041						43
54	15.90					1963	2067	2171	2314	2587	2730					48
60	19.64					2418	2548	2678	2860	3198	3380					54
66	23.76						3094	3237	3458	3861	4082	4368				59
72	28.27						3679	3848	4121	4589	4859	5200	5512			64
78	33.18							4524	4823	5395	5837	6097	6474	6825		70
84	38.48							5239	5603	6253	6617	7072	7501	7904	8658	75
90	44.18								6435	7176	7592	8125	8619	9074	9945	80
96	50.27								7319	8164	8645	9243	9802	10335	11323	86
102	56.75								8268	9217	9737	10426	11063	11661	12779	91
108	63.62								9256	10335	10933	11700	12402	13078	14313	96
114	70.88									11518	12181	13026	13819	14573	15964	101
120	78.54									12766	13494	14443	15314	16146	17680	107
132	95.08									15444	16328	17472	18525	19526	21398	117
144	113.10									18382	19435	20800	22061	23244	25467	128

TABLE No. 11.

Diameter	Area (A) square feet.	HEIGHT OF CHIMNEY. WATER-HEATING SURFACE IN BOILERS. (0.3 lb. of coal per square foot of W. H. S. per hour.) 50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′*	225′	250′	300′	Equivalent square chimney side of square.
Inches.																Inches.
18	1.77	563	607	650	693	....	....	....	....	....	....	....	....	....	....	16
21	2.41	737	823	867	910	....	....	....	....	....	....	....	....	....	....	19
24	3.14	953	1040	1127	1213	1300	....	....	....	....	....	....	....	....	....	22
27	3.98	1213	1343	1430	1517	1647	....	....	....	....	....	....	....	....	....	24
30	4.91	1517	1647	1777	1907	2037	2123	....	....	....	....	....	....	....	....	27
33	5.94	....	1993	2167	2297	2427	2557	2687	....	....	....	....	....	....	....	30
36	7.07	....	2383	2557	2730	2903	3033	3207	3423	....	....	....	....	....	....	32
39	8.30	....	....	2990	3207	3423	3597	3770	4030	....	....	....	....	....	....	35
42	9.62	....	....	3510	3760	3943	4160	4420	4680	5200	....	....	....	....	....	38
48	12.57	....	....	....	4853	5157	5460	5720	6110	6803	....	....	....	....	....	43
54	15.90	....	....	....	....	6545	6890	7237	7713	8623	9100	....	....	....	....	48
60	19.64	....	....	....	....	8060	8493	8927	9533	10660	11267	....	....	....	....	54
66	23.76	....	....	....	....	....	10313	10790	11527	12870	13607	14562	....	....	....	59
72	28.27	....	....	....	....	....	12263	12827	13737	15297	16197	17333	18373	....	....	64
78	33.18	....	....	....	....	....		15080	16077	17983	19457	20323	21580	22750	....	70
84	38.48	....	....	....	....	....	....	17463	18677	20843	22057	23573	25003	26347	28860	75
90	44.18	....	....	....	....	....	....	....	21450	23920	25307	27083	28730	30247	33150	80
96	50.27	....	....	....	....	....	....	....	24397	27213	28817	30810	32673	34450	37743	66
102	56.75	....	....	....	....	....	....	....	27560	30757	32457	34753	36877	38871	42597	91
108	63.62	....	....	....	....	....	....	....	30853	34450	36443	39000	41340	43593	47710	96
114	70.88	....	....	....	....	....	....	....	....	38393	40603	43420	46063	48910	53213	101
120	78.54	....	....	....	....	....	....	....	....	42553	44980	48143	51047	53820	58933	107
132	95.03	....	....	....	....	....	....	....	....	51480	54427	58240	61750	65087	71327	117
144	113.10	....	....	....	....	....	....	....	....	61273	64783	69333	73537	77480	84890	128

This table has been calculated by D. K. Clark's rules.

TABLE No. 12.

Height.	Diameter of Flue.	Top sectional area of flue in feet.		Coal per hour.	Area of grate.
		Area.	Per lb. coal per hour.		
Feet.	Inches.			Pounds.	Square feet.
40	16	1.39	1.41	142	9.5
45	18	1.77	1.34	190	12 7
50	20	2.19	1.27	248	16.5
55	22	2.63	1.21	314	20.9
60	24	3.14	1.16	390	26.0
65	26	3.69	1.11	477	31.7
70	28	4.26	1.07	574	38.3
75	30	4.91	1.04	682	45.5
80	32	5.60	1.00	801	53 4
85	34	6 29	.97	932	62.1
90	36	7.09	.95	1076	71.7
95	38	7.89	.92	1231	82.1
100	40	8.71	.90	1394	93.0
105	42	9.62	.88	1582	105.5
110	44	10.57	.86	1777	118.4
115	46	11.52	.84	1985	132.3
120	48	12.86	.82	2208	147.2
125	50	13.65	.80	2446	163.1
130	52	14.73	.79	2698	179.8
135	54	15 90	.77	2964	197.6
140	56	17.12	.76	3247	216.4
145	58	18.32	.74	3544	236.2
150	60	19.63	.73	3858	257.2
155	62	20.99	.72	4187	279.1
160	64	22.31	.71	4533	302.2
165	66	23.76	.70	4896	326.4
170	68	25.24	.69	5275	351.6
175	70	26.69	.68	5672	378 1
180	72	28.27	.67	6086	405.7
185	74	29.90	.66	6517	434.5
190	76	31.47	.65	6967	464.5
195	78	33.18	.64	7434	495.6
200	80	34.94	.63	7920	526.6

RATE OF COMBUSTION DUE TO HEIGHT OF CHIMNEY.

Trowbridge's "Heat and Heat Engines" gives the following table showing the heights of chimneys for producing certain rates of combustion per square foot of section of the chimney-flue. It is best adapted to chimneys where a good grade of large-sized anthracite coal is used.

TABLE No. 13.

Height of chimney in feet.	Lbs. of coal burned per hour per square foot of section of chimney flue.	Lbs. of coal burned per square foot of grate, the ratio of grate area to chimney flue area being 8 to 1.	Height of chimney in feet.	Lbs. of coal burned per hour per square foot of section of chimney flue.	Lbs. of coal burned per square foot of grate, the ratio of grate area to chimney flue area being 8 to 1.
20	60	7.5	70	126	15.8
25	68	8.5	75	131	16.4
30	76	9.5	80	135	16.9
35	84	10.5	85	139	17.4
40	93	11.6	90	144	18.0
45	99	12.4	95	148	18.5
50	105	13.1	100	152	19.0
55	111	13.8	105	156	19.5
60	116	14.5	110	160	20.0
65	121	15.1	....	....	....

Dr. R. H. Thurston's rule for the rate of combustion for a given height of chimney (Trans. A. S. M. E., vol. xi., p. 991) is: Subtract one from twice the square root of the height, and the result is the rate of combustion in pounds per square foot of grate per hour, for anthracite coal; or rate $= 2\sqrt{H} - 1$, in which H is the height of chimney in feet.

This rule gives the following table:

$H =$	50	60	70	80	90	100	110	125	150	175	200
$2\sqrt{H} - 1 =$	13.14	14.49	15.73	16.89	17.97	19	19.97	21.36	23.49	25.45	27.28

The results agree closely with Trowbridge's table given above. In practice, however, the high rates of combustion for high chimneys given by the formulæ are seldom obtained, for the reason that with high chimneys there are long horizontal flues, serving many boilers, and the friction and interference of the currents of gases from the different boilers diminish the intensity of the draft at the boiler from what it was at the chimney.

In a battery of several boilers connected to a chimney 150 feet in height there has been found $\frac{3}{4}$ inch of water draft at the boiler nearest the chimney, and only $\frac{1}{4}$ inch at the boiler farthest from it.

The first boiler was wasting fuel from an excessive temperature of the chimney gases, 900° Fahr., having too large a

grate surface for the draft, and the last boiler was working below its capacity, and with poor economy, on account of poor draft.

Theron Skeel gives the following relative amounts of coal that can be burned in the same time with chimneys of various heights:

Height in feet..........	120	100	80	60	40	20
Relative amount of fuel..	100	90	80	70	57	40

J. J. DeKinder finds the best results to be obtained by using chimneys of the following heights:

75 feet for free-burning bituminous coal.
100 feet for free-burning bituminous slack.
115 feet for slow-burning bituminous coal.
125 feet for anthracite pea coal.
150 feet for anthracite buckwheat coal.

with a draft for anthracite coal of 0.75 to 0.88 inch of water.

This agrees with the conclusions of Emery and Hague.

AIR-SPACE IN GRATES.

The successful performance of a chimney depends upon very many local conditions, among which, and very important, is the amount of air supplied to the burning fuel and allowed to pass through it.

The following list gives the proper size of air-space and thickness of metal in the bar for different fuels.

$\frac{1}{4}$-inch opening and $\frac{3}{8}$-inch iron for screenings.
$\frac{3}{8}$-inch opening and $\frac{3}{8}$-inch iron for buckwheat coal.
$\frac{1}{2}$-inch opening and $\frac{1}{2}$-inch iron for nut or pea coal.
$\frac{5}{8}$-inch opening and $\frac{1}{2}$-inch iron for stove coal.
$\frac{3}{4}$-inch opening and $\frac{1}{2}$-inch iron for egg coal.
$\frac{7}{8}$-inch opening and $\frac{1}{2}$-inch iron for broken coal.
1-inch opening and $\frac{1}{2}$-inch iron for lump coal.
$\frac{1}{4}$-inch opening and $\frac{3}{8}$-inch iron for sawdust.
$\frac{3}{8}$-inch opening and $\frac{3}{8}$-inch iron for sawdust.
$\frac{1}{2}$-inch opening and $\frac{1}{2}$-inch iron for shavings.
$\frac{5}{8}$-inch opening and $\frac{1}{2}$-inch iron for shavings.

For bituminous coal, $\frac{5}{8}$ or $\frac{3}{4}$-inch opening and $\frac{1}{2}$-inch iron.

VOLUME OF AIR PASSING THROUGH CHIMNEY.

According to Professor H. B. Gale, the velocity for maximum draft in chimneys is between six and fourteen feet per second, depending on the height of the chimney and temperature of the escaping gases; in brick-stacks it sometimes is as low a rate as three feet per second. The exact rate at which the best draft is produced depends on so many variables, such as flue temperatures, grate air-space, kind of conditions of fuel, etc., that it is probably not the same in any two chimneys or power plants.

VELOCITY OF GASES.

Lang recommends "for velocity of chimney gases, V_n, 13.12 feet per second; in sheltered locations 9.84 feet per second.

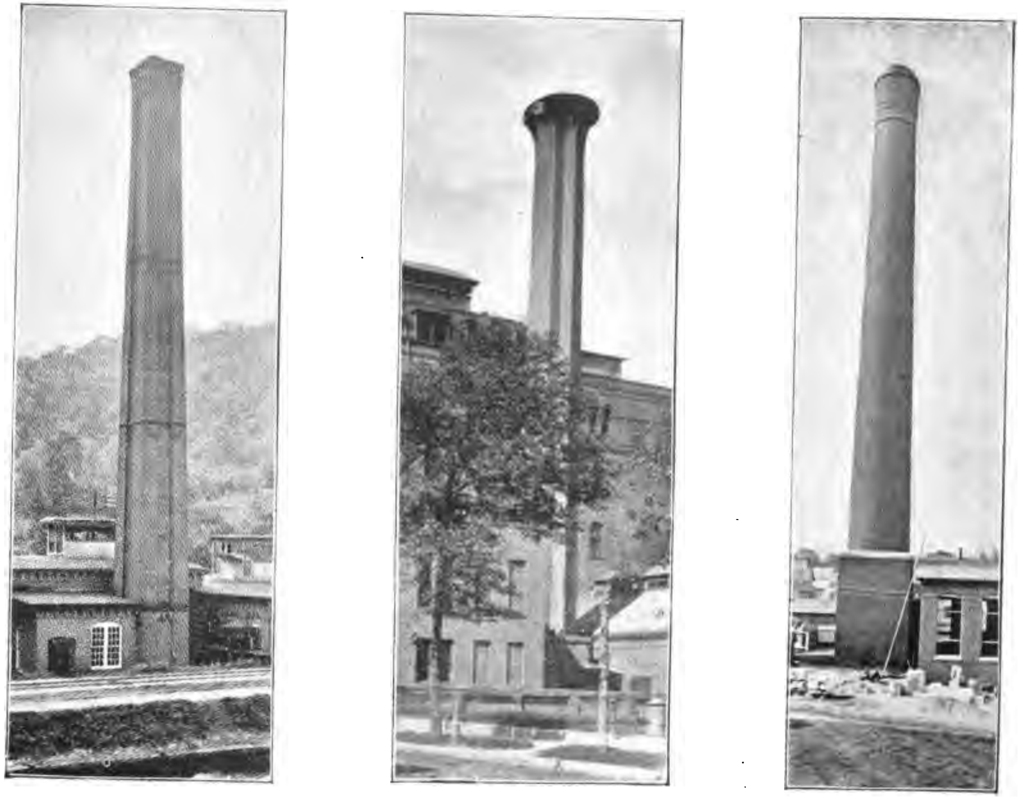
If prevailing winds come over steep mountains and fall on the top of the chimney, then V_n must be correspondingly increased from 19.68 to 22.96 feet per second; or the top of the chimney must be provided with proper covers for such unfavorable directions (wind caps, etc.).

With good wind caps V_n may be reduced from 4.92 to 5.65 feet a second.

Wind caps, on account of their dangerous position, are only recommended in exceptional cases.

If a number of boiler-furnaces discharge their gases in one and the same chimney, then V_n must be increased for the full working number, so that in case there are less than the whole number of boilers under fire a sufficient exhaust velocity of the gases will still be obtained. In place of the average value of $V_n = 13.12$ feet per second; the following values may be substituted:

For 3 boilers, $V_n = 16.40$ ft. per sec. = 984.0 ft. per minute.
" 7 " $V_n = 19.68$ " " = 1180.8 " "
" 12 " $V_n = 22.96$ " " = 1377.6 " "
" more, 12 + X boilers, $V_n = 22.96 + \frac{X \times 3.28}{20}$ ft. a second.



ILLUS. No. 2.
THREE BRICK CHIMNEYS.

WIND-PRESSURE.

The scale of the Smithsonian Institution at Washington for the estimation and description of the velocity and pressure of the wind, calculated by Smeaton's Rule, is as follows:

Divide the square of the velocity in miles per hour by 200; the quotient is the pressure in pounds per square foot.

TABLE No. 14.

Grade.	Velocity in miles per hour.	Pressure per square foot in lbs.	Name.
0	0	0.0	Calm.
1	2	0.02	Very light breeze.
2	4	0.08	Gentle breeze.
3	12	0.75	Fresh wind.
4	25	3.00	Strong wind.
	30	4.50	
5	35	6.00	High wind.
	40	8.00	
6	45	10.00	Gale.
	50	12.5	
7	60	18.00	Strong gale.
8	75	28 2	Violent gale.
	80	32.00	
9	90	40.5	Hurricane.
10	100	50.00	Most violent hurricane.

In the United States the general practice is to assume fifty pounds wind-pressure per square foot as the highest to be considered.

No record of such a high pressure has been heard of, or is likely to be, except in the extreme hurricane, with cyclonic conditions present, as in the East St. Louis, Mo., tornado of 1896, when the brick chimney of the Electric Light Section was partially destroyed and blown down.

From calculations made since the occurrence, the force of the wind must have been about ninety pounds per square foot.

During the Galveston, Tex., tornado of September, 1900, the barometer dropped to 27.3 inches, and the velocity of the wind was reported by a United States Engineer to have been as high as 100 miles per hour.

The *Engineer*, London, says: the pressure of the wind on plane surfaces has been found by experiments to be approximately:

$$q = \frac{v^2}{430} \cos i.$$

v = velocity of wind in feet per second.
i = angle between the normal to the plane and the direction of the wind.
q = pressure in pounds per square foot of plane.

The above, of course, does not apply to curved surfaces.

CHAPTER V

FOUNDATION MATERIALS. BRICK CHIMNEY MATERIALS

LOGICALLY and from an engineering stand-point, the first detail of chimney construction is the foundation.

Before considering this topic, a brief statement of the qualities and strengths of various soils, with reference to their ability to support foundations, is requisite.

BEARING POWER OF SOILS.

The building laws of New York City allow 4 tons per square foot as a safe load for "good solid natural earth."

The laws of Chicago specify $1\frac{3}{4}$ tons for pure clay, fifteen feet or more thick; 2 tons for pure dry sand, fifteen feet or more thick; and $1\frac{1}{2}$ tons for a mixture of clay and sand of the same depth.

Ordinary practice gives the following:

200 tons per square foot for solid bed rock.

5 to 25 tons per square foot for rock broken, but well compacted.

4 tons per square foot for pure clay fifteen feet or more thick.

1 ton per square foot for soft wet clay.

8 tons per square foot for gravel well packed and confined.

4 tons per square foot for pure dry sand well packed and confined.

2 tons per square foot for pure dry sand in its natural bed.

$\frac{1}{2}$ ton per square foot for quicksands and marshy soils.

PILING.

Piling must be resorted to when the soil is very sandy or loose.

Piles should be of spruce, not less than six inches in diameter at the smaller end, and should be driven by a drop-hammer weighing not less than 2,000 pounds.

The broom and splinters should be removed from the head of the pile for the last blow.

The heads of the piles should be sawed off level and capped with an oak grillage, or filled around with concrete.

There has been no satisfactory determination made of the safe load on piles, and each engineer is obliged to use his own judgment.

A test reported in *Engineering News*, July, 1893, says: four piles, 13 inches in diameter, 80 square inches area, held up 50.7 tons each without settling.

We give the following formulæ, for the benefit of those who care to use them:

Let R = weight of ram in pounds.
h = fall of ram in feet.
s = depression at last blow in feet.
e = average depression for 100 blows—in inches.
P = weight of pile in pounds.
L = carrying capacity of driven pile in pounds.

(29) Safe load in pounds $= \dfrac{Rh}{(P+R)s}e$. (Dutch formula).

(30) Safe load in pounds $= \frac{1}{6}\left(\dfrac{Rh}{\frac{1}{12}+s}\right)$. (*Eng. News*, Feb., 1891.)

(31) $L = \frac{1}{6}\left(\dfrac{Rh}{s}\right)$. (L. P. Church in *Mechanics*.)

(32) $L = 32R\sqrt{h} - c$. (Haswell, 1894); *
where c is a constant having a value of from three to six according to the nature of the soil.

(33) $L = \dfrac{2Rh}{12s+1}$. (Wellington.)

(34) $L = \dfrac{\sqrt[3]{h} \times R \times .026}{12s+1}$. (Trautwine.)

As a factor, Trautwine recommends that for piles thoroughly driven in firm soils, one-half of the above load be taken; in river, mud, or marsh (piles not driven to rock bottom), the safe load be restricted to one-sixth of L.

* Haswell, 1900, gives $L = 8R\sqrt{h} + 1.25$

$$(35)\quad L=\frac{\text{fall of hammer in inches} \times \text{weight of ram in net tons}}{\text{depression at last blow in inches} \times 8}.$$

(Sanders.)

This formula applies to piles driven until penetration is small and nearly equal for successive blows.

Building laws of these cities give the following:

Philadelphia, small end 5 inches, head 12 inches, spaced not over 30 inches centre to centre, 20 net tons per pile.

New York, small end 5 inches, spaced not over 30 inches centre to centre, 20 net tons per pile.

Chicago, 25 net tons per pile, driven to rock or hardpan bearings.

Buffalo, small end 6 inches, spaced not over 36 inches centre to centre, 25 net tons per pile.

CONCRETE.

Concrete is largely used as a subsidiary foundation.

The Metropolitan Water Board's specifications for this material are as follows: "Concrete shall be composed of one part by measure of American natural hydraulic cement, two parts of clean, sharp sand, and five parts of clean screened broken stone, or clean screened gravel.

"The stone for the concrete shall be free from clay, dirt, or other objectionable material; no stone shall be greater than two and one-half inches, and but very few less than one-quarter inch in their greatest dimensions.

"The mixing shall be done in proper boxes, in a manner satisfactory to the engineer.

"After the materials are wet, the work must proceed rapidly until the concrete is in place, and is so thoroughly rammed that water flushes to the surface, and all the interstices between the stones are entirely filled with mortar.

"It shall be allowed to set a sufficient time, to be determined by the engineer, before walking over, or working upon it shall be permitted.

"All trenches or foundations must be kept free of water while concrete is being placed therein.

"All cement used in the work shall be of the best quality of American natural hydraulic cement, and equal in quality to the best Rosendale cement; it must be made by manufacturers

of established reputation, and must be fresh, very fine ground, and put up in well-made casks.

"For exposed stone masonry, Portland cement, mixed in the same proportions as the American cement concrete, shall be used; all other stone masonry should be laid in American cement concrete of second quality, mixed in proportion, by measure, of one part of cement to two parts of sand for both mortars."

The building laws of Chicago will not allow more than four tons per square foot on concrete foundations.

Boston and New York specify a minimum thickness of twelve inches.

Using a factor of safety of five, the safe load per square foot, for concrete one month old, is three tons; for concrete six months old, is twelve tons; for concrete one year old, is sixteen to twenty tons.

Chimney foundations are sometimes made of large stones laid on a bed of concrete, and in any case, whether of concrete, stone, or both, they should be large enough to prevent unequal settling; the pressure on the foundation being largely concentrated on the leeward side, and the prevailing winds therefore are apt to have the effect of canting the chimney to one side, unless a broad foundation is furnished.

For dimensions of foundations, and descriptions of several in particular, see pages 36 to 116.

Walls laid in lime and cement mortar: New York, 23,000 pounds per square foot, 160 pounds per square inch.

PIERS.

Building laws of Boston allow 6 to 20 times least diameter for the height, also laid in 1 part cement, 2 parts sand, 26,000 pounds per square foot; laid in 1 part cement, 4 parts sand, 20,000 pounds per square foot; laid in lime mortar, 14,000 pounds per square foot; for "light hard" brick, two-thirds of the above loads are allowable.

Professor Ira O. Baker* says, "safe loads for good brick, in lime mortar, 40,000 pounds per square foot; in cement, 60,000 pounds per square foot.

* Expanded Metal and its Uses in Fire-proof Construction.

In United States Government tests, piers built in lime mortar have cracked at a load of 1,200 pounds per square inch, or 172,800 pounds per square foot.

TABLE No. 15.

UNITED STATES GOVERNMENT TESTS, WATERTOWN ARSENAL.

Breaking load on common brick piers, laid in a mortar composed of one part cement to two parts clean sharp sand.

Height (feet).	Size of pier (inches).	Area (square inches).	Breaking load (pounds per square inch).
10	8 × 8	57.38	1500
8	12 × 12	130.53	1461
10	12 × 12	132.25	1347
10	12 × 12	108.03	1457
10	16 × 16	238.70	964
10	16 × 16	244.92	1010
12½	12 × 12	134.56	1622
12½	12 × 12	131.67	1468
Laid in lime one part, sand three parts.			
10	12 × 12	132.25	1511
10	12 × 12	115 44	1807
10	12 × 16	192.00	773 *

* Face brick; showed cracks at a load of 516 pounds per square inch.

FIRE AND RED-BRICK-WORK.

Sizes of fire-brick: 9-inch straight, 9 × 4½ × 2½ inches.
Soap, 9 × 2½ × 2½ inches.
Checker, 9 × 3 × 3 inches.
2-inch, 9 × 4½ × 2 inches.
Split, 9 × 4½ × 1¼ inches.

A 9-inch straight brick weighs 7 pounds, and contains 100 cubic inches, its specific gravity is 1.93.

One cubic foot of wall requires 17 9-inch straight bricks, and weighs 120 pounds. One cubic yard requires 460 9-inch bricks.

One ton of fire-clay will lay 3,300 ordinary bricks.

Fire-bricks should be used where a temperature greater than 600° Fahr. is to be withstood.

English fire-brick measure 9 × 4½ × 2¼ inches.

A. T. Byrne says: * "To secure the best results, fire-brick should be laid in the same clay from which they are manufactured.

"It should be used in a thin paste, and not as a mortar: the thinner the joint the better the furnace wall. The brick should be dipped in water as they are used, so that when laid they will not absorb the water from the clay paste.

"They should then receive a thin coating of the prepared fire-clay, and be carefully placed in position with as little of the fire-clay as possible."

Ordinary red bricks measure $8\frac{1}{4} \times 4 \times 2$ inches, or 26 bricks to the cubic foot. The average weight is $4\frac{1}{2}$ pounds.

An $8\frac{1}{4}$-inch wall requires 14 bricks per superficial foot.

A $12\frac{3}{4}$-inch wall requires 21 bricks per superficial foot.

A 17-inch wall requires 28 bricks per superficial foot.

A $21\frac{1}{2}$-inch wall requires 35 bricks per superficial foot.

SAFE LOADS.—*Red brick.—Summary of some municipal building laws. New York, Chicago, and Boston.*

Walls: Hard-burned red brick, laid up in a mortar composed of one part of cement to two parts clean sharp sand:

Boston.......30,000 lbs. per sq. ft., 207 lbs. per sq. in.
New York....30,000 lbs. per sq. ft., 207 lbs. per sq. in.
Chicago......25,000 lbs. per sq. ft., 173 lbs. per sq. in.

Walls laid in a mortar composed of one part of cement to four parts of clean sharp sand:

Boston ....24,000 lbs. per sq. ft., 166 lbs. per sq. in.
Chicago......18,000 lbs. per sq. ft., 125 lbs. per sq. in.

Walls laid in lime mortar:

Chicago......13,000 lbs. per sq. ft., 90 lbs. per sq. in.
Boston.......16,000 lbs. per sq. ft. 111 lbs. per sq. in.
New York....16,000 lbs. per sq. ft., 111 lbs. per sq. in.

Expansion of Fire-brick in Chimney.—Eng. Rec., vol. xxix., p. 400, H. N. Brinckerhoff says: It varies from nothing to 2 to 3 inches in 75 feet in height, also that in lined steel chimneys 4 inches in 200 feet is not likely to occur.

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* Inspector's Pocket Book.

Twenty cubic feet = 16 bushels of sand, 4 cubic feet = 32 struck bushels of quicklime, will make 22½ cubic feet of mortar and will lay 1,000 2 × 4 × 2¼-inch bricks, with ⅜ to ½-inch joints.

A good bricklayer will in a day of ten hours lay 1,500 brick if provided with a laborer to keep him supplied with materials, but in chimney-work the number of bricks laid will depend on design of chimney and elevation above ground of scaffold, from which they are laid.

John C. Trautwine, Esq., furnishes the following directions for cement mortar:

A barrel of cement, 300 pounds, and two barrels of sand (six bushels or 7½ cubic feet) mixed with about half a barrel of water, will make about 8 cubic feet of mortar sufficient for

192 square feet of mortar, joint ½ inch thick;
288 square feet of mortar, joint ⅜ inch thick;
384 square feet of mortar, joint ¼ inch thick;
768 square feet of mortar, joint ⅛ inch thick;

or, to lay 1 cubic yard, or 522 bricks of 8¼ × 4 × 2 inches with joints ⅜ inch thick, or a cubic yard of rubble stone-work. The quantity of sand may be increased to 3 or 4 measures for ordinary work.

Two barrels of cement and two barrels of sand will be sufficient to lay 1,000 bricks.

Five pounds of salt added to each 20 gallons of water used with cement, will prevent its freezing at a temperature of 10° below zero.

It quickens the hardening and does not materially reduce the ultimate strength.

LINING.

If the heat of the gases exceed 300° C. or 572° Fahr. then the building of a so-called lining of the shell of a thickness = 0.09 meter (3.53 inches) to 0.25 meter (9.84 inches), varying according to the chimney heat and degree of heat in the entering gases, is to be recommended.

Gases below 250° C. (482° Fahr.) do not demand a fire-brick lining, except up to a short distance above where the flue enters the chimney. (G. Lang.)

The latter is about all that is done in brick chimneys in the United States.

Rarely being over 9 inches thick at the bottom for 30 feet in height, or less, and 4½ inches thickness for 30 feet above it, we also seldom see any double-shell brick chimney lined with fire-brick to a greater height than 20 to 30 feet above breeching or top of entering flue.

A single-shell brick chimney 225 feet 9 inches, p. 89, has 56 feet of 9-inch and 60 feet of 4½-inch fire-brick lining.

Steel chimneys are frequently lined with hard-burned red brick, sometimes with fire-brick, generally leaving an inch space between lining and shell to be filled with sand.

All fire-brick linings should have room for expansion, and for removal of a portion at one time.

FOUNDATIONS.

Professor Lang, of Hanover College, Germany, says: The bounding planes of the sides of foundations should be inclined, enlarging the body of masonry as it deepens. Instead of a plane, the inclination may be made by use of a step construction. The proportions of the foundation should be such that the permissible load per square foot on the earth or soil found in the particular locality shall not be exceeded, and, also, that the wind-pressure against the chimney-shaft shall not unduly increase the foundation load at any point. The inclination of the bounding sides with the horizontal should not be greater than 60 degrees. It may be assumed that the supporting and sustaining capacity of earth of uniform character increases gradually with its depth.

In order that both the dead load and the effect of the wind-pressure may be properly taken care of, Hotop gives these formulæ:

Where H_u = depth of foundation below ground level;
B_u = breadth of the bottom of foundation;
H_c = height of chimney above the top of foundation;
and S_u = thickness of bottom plate of foundation,

$$H_u = \frac{H_c}{8} \text{ and } B_u = \frac{H_c + H_u}{8}$$

For especially wide chimneys, the values of H_u and B_u should be enlarged proportionally.

Gaping of joints in chimneys is almost entirely avoided when the greatest pressure on the foundation does not exceed 35.55 pounds per square inch or 5120 pounds per square foot. The base of the foundation, or foundation plate, should have a thickness $S_u \geqq 1.64 + 0.01\,H$, where all dimensions are in feet. If the angle of the sides to bottom of the foundation should be greater than 60 degrees, it should be strengthened by steel beams or railroad rails placed crosswise in the concrete.

In looking over some tests, the writer finds that in compression tests of cubes of cement concrete the corners of the cubes and their sides break off, or slough off, leaving the angle somewhat less than 60 degrees; this bears out Professor Lang's statement. Thus, when designing footings or foundations of concrete, with no metal in them, it is of no advantage to have the angle of the bounding sides to the base much less than 60 degrees. Again, there is no advantage in enlarging the foundation plate beyond what that angle will give, unless metal reinforcement is used.

The foundation of masonry for the brick-lined steel chimney for the Maryland Steel Works was large-dimensioned stone, quarry faced, with dressed arrises, set in a mortar of one part Portland cement and three parts of sand by measure.

The foundation of a brick chimney erected in 1859 for the Chicago Refining Company, 151 feet high, 12 feet square at the base, is as follows: The base, two courses of heavy-dimensioned stone, is bedded upon the surface gravel near the mouth of the river, there recently deposited by the lake. The mortar employed in the joints between the stones was roofing gravel and cement. The area of the base is 256 square feet, the weight of the chimney, inclusive of the base, is 625 tons, giving a pressure of 34 pounds to the square inch, 2.45 tons per square foot.

TABLE No. 16.

TABULATION OF COEFFICIENTS OF EXPANSION OF STONES, AS DETERMINED IN WATER BATHS.

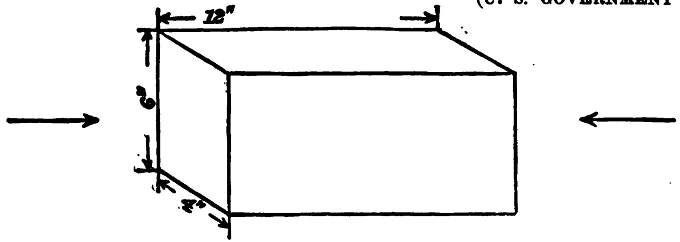
Description of Stones.			Original gauged length in air.	Temperature of baths, F.			Gauged lengths.			Coefficient of Expansion.
Name.	Quarry.	Location.		Hot.	Cold.	Difference.	Hot.	Cold.	Difference.	
			Inches.	Degree.	Degree.	Degree.	Inches.	Inches.	Inch.	
Hoosier Buff Oolitic limestone		Indiana	20 0033	178	33.5	144.5	20.0168	20.0059	.0109	.00000375
Limestone		Indiana	20.0084	177	33 5	143.5	20.0223	20.0115	.0108	.00000376
Marble		Vermont	19 9989	203	34	169	20.0239	20.0117	.0122	00000361
Marble	Lee	Massachusetts	20.0061	189.5	33.5	156	20.0236	20.0061	.0175	.00000562
Red sandstone	Potomac Red Sandstone Co.	Maryland	20.0034	183	33 5	149 5	20.0187	20.0035	.0152	.00000501
Red sandstone	Brainard Quarry Co., Portland	Connecticut	19.9912	180	33.5	146.5	20.0105	19.9951	.0154	.00000526
Sandstone		Ohio	20.0019	183	33.5	149 5	20.0187	20.0001	.0186	.00000622
Slate	Monson	Maine	19.9954	194	34	160	20.0108	19.9950	.0158	.00000500
Bluestone		New York	20.0052	192	33.5	158.5	20.0340	20.0151	.0189	.00000596
Granite	Worcester Quarry, Milford	Massachusetts	20.0023	183	33.5	149.5	20.0166	20.0044	.0122	.00000408
Granite*	Quincy	Massachusetts	19.9951	199	33.5	165.5	20.0079	19.9953	.0126	.00000381
Granite	Rockport Granite Co., Cape Ann	Massachusetts	19.9303	181	33.5	147.5	19.9401	19.9310	.0091	.00000311
Red brick, No. 1	Manufactured		6.0852	184	34	150	6.0874	6.0842	.0032	.00000351
Red brick, No. 2	Manufactured		6 0109	184	34	150	6.0129	6.0106	.0023	.00000255
Red brick, No. 3	Manufactured		5.9396	184	34	150	5.9417	5.9394	.0023	.00000258
Red brick, No. 4	Manufactured		6.0204	184	34	150	6.0224	6.0195	.0029	.00000321
Fire brick, No. 1	Manufactured		5.9968	184	34	150	5.9994	5.9968	.0026	.00000289
Fire brick, No. 2	Manufactured		5.9988	184	34	150	6.0010	5.9988	.0022	.00000244
Ashler brick E_1	Manufactured		10.0218	185	34	151	10.0245	10.0217	.0028	.00000185
Hollow fireproof building brick	Manufactured		10 0036	185	34	151	10,0076	10.0032	.0044	.00000291

* Quarried about the year 1840. Specimens taken from the old post-office building. State Street, Boston, Mass.

United States Government Tests at Watertown Arsenal.

COMPRESSION TESTS OF NATURAL STONES.

(U. S. GOVERNMENT TESTS.)



Specimens tested on bed, except the bluestone and the slate, which were tested on edge.

The ends were faced with plaster of Paris, to secure even bearings in testing machine.

TABLE No. 17.

No. of test.	Kind of stone.	Dimensions.			Section-al area.	First crack.	Ultimate strength.		Remarks
		Height.	Compressed surface.				Total.	Per square inch.	
		Inches.	*Inches.*	*Inches.*	*Sq. in.*	*Pounds.*	*Pounds.*	*Pounds.*	
5089	Hoosier bluff limestone..	12.00	6.01	4.01	24.1	164.000	171,200	7,104	
5090	Indiana limestone.......	12.00	6.00	4.02	24.1	166.700	179,300	7,440	
5091	Vermont marble	12.02	5.99	4.00	24.0	287,700	287,700	11,987	
5092	Lee marble.............	11.99	5.88	3.98	23.4	422,300	422.300	18.047	
5093	Potomac red sandstone..	11.97	6.00	4.01	24.1	458,500	458.700	19.035	
5094	Portland red sandstone..	12.02	6.00	3.97	23.8	239,800	253,600	10.655	
5095	Ohio sandstone.	12.00	5.99	3.98	23.8	202,900	206,100	8.660	
5096	Monson slate.....	12.00	6.06	4.05	24.5	160.000	478,000	19,510	
5097	North River bluestone...	12.08	6.02	3.93	23.7	608.000	608,000	25.654	
5098	Worcester granite.......	12.02	6.01	4.01	24.1	608,100	608,100	25,232	
5099	Quincy granite.........	12.03	6.00	4.00	24.0	134,000	462.800	19,283	The tests of these specimens were characterized by a succession of pieces flaking off after the first cracks were observed to appear.
5100	Cape Ann granite.......	11.93	6.00	4.00	24.0	173,000	487,100	20,296	

The foundation of a brick chimney erected in 1872 for the McCormack reaper works, 160 feet high, 14 feet square at the base, with a flue 6 feet 8 inches in diameter, is as follows: The base is 25 feet square; area, 625 square feet; the weight of the chimney and the base is approximately 1,100 tons; the pressure on the soil is 24.33 pounds per square inch, 1.75 tons per square foot. Soil was dry, hard clay. This loading is very light.

Foundations for self-sustaining steel chimneys are of necessity of greater bearing surface than for brick chimneys, and will be treated under steel chimneys.

CHAPTER VI

STEEL CHIMNEYS—THEORY PERTAINING TO SAME, AND EXAMPLES FROM EXISTING STRUCTURES

STEEL CHIMNEYS.

THE cheapest chimney that can be erected if ground-space is plenty, is a straight steel tube, held up by one or two sets of guy-rods or wires, four or six in a set. These guys should be fastened to an angle-iron or band at two-thirds the height, and if two sets are used, also at one-third the height. They should be anchored at a distance from the base equal to the height of the band above the ground. Boiler blank flue-heads, 16 to 24 inches larger in diameter than the chimney, and $\frac{5}{8}$ to $\frac{3}{4}$-inch in thickness, make good bed-plates. If cast-iron bed-plates are used, they should be at least one inch thick. The foundation should extend at least 12 inches above the ground level, and should be sunk 4 feet below ground level, and spread out on the bottom to about twice the diameter of the chimney. An iron or steel casing is superior to a brick one, in that it does not leak and draw in cold air, thus impairing the draft. Moreover, when the ordinary chimney is working at its full capacity the velocity of the ascending column of gases is so great that very little heat is lost by radiation through the shell, even though the latter be without any lining, which is quite common.

It is scarcely necessary to say that steel chimneys are always round. For guy-rods, $\frac{1}{2}$-inch or $\frac{3}{4}$-inch iron is a common size. For guy-wires, not over 1 inch in diameter should be used. The following table will give some useful data. Whether rods or wires are used, a turnbuckle is necessary for adjusting the tautness of the connection.

TABLE No. 18.

STANDARD HOISTING ROPE—CRUCIBLE STEEL, NINETEEN WIRES TO THE STRAND.

Circumference. Inches.	Diameter. Inches.	Weight per foot of rope with hemp centre Lbs.	Breaking strain in tons of 2,000 lbs.	Safe working load in tons of 2,000 lbs.
$3\frac{1}{2}$	$1\frac{1}{8}$	2.00	40	6
$3\frac{1}{8}$	1	1.58	32	5
$2\frac{3}{4}$	$\frac{7}{8}$	1.20	24	4
$2\frac{5}{8}$	$\frac{3}{4}$	0 88	18	3
2	$\frac{5}{8}$	0.60	14	2
$1\frac{3}{4}$	$\frac{9}{16}$	0.44	$9\frac{1}{2}$	$1\frac{1}{2}$
$1\frac{1}{2}$	$\frac{1}{2}$	0.35	$7\frac{1}{2}$	1
$1\frac{3}{8}$	$\frac{7}{16}$	0.28	6	$\frac{3}{4}$
$1\frac{1}{8}$	$\frac{3}{8}$	0.26	5	$\frac{5}{8}$

GUYED STEEL CHIMNEYS.

"*Rule of Thumb*" *for Finding Diameter of Guy Wires for Steel Chimneys.* (*Engineering Mechanics*, October, 1893.)

Multiply the height of chimney in feet by its diameter in inches, and take the square root of the product. Divide this by 100, and the quotient is the least allowable diameter in inches for each of four guys.

TABLE OF THICKNESS BY GAUGE OF STEEL FOR GUYED CHIMNEYS.

Diameter—inches...	18	20	24	26	28	30	32	32	34	36
Height—feet.......	40	45	50	50	55	60	65	70	70	75
Thickness—gauge..	16	16	14 & 16	14	14	12 & 14	12 & 14	12 & 14	10 & 12	10 & 12

E. P. Allis & Co.

WEIGHT PER FOOT OF STEEL-RIVETED TUBES FOR GUYED CHIMNEYS.

Diameter—inches.........	10	12	14	16	20	22	24	26	28	30
No. 16 W. G., Wt. per foot.	7.20	8.66	9.58	11 68	13.75	15.00	16.25	17.5	18.75	20.00
No. 14 W. G., Wt. per foot.	9.40	11.11	13.69	15.00	18.33	20.00	21.66	23.33	25.00	26.66

Circular boiler heads make good bases for guyed steel chimneys. The table on pages 42 and 43 applies to such cases.

SELF-SUSTAINING STEEL CHIMNEYS.

The self-sustaining steel chimney is a feature of a great many modern power plants, because of its many advantages over a brick chimney.

Among these advantages are: less floor or ground-space occupied, that is above the ground; ease and rapidity of construction and erection; because it weighs less than a brick

chimney of like capacity, it is better adapted to soils of low load-sustaining power; the steel shaft presents a smaller area to the wind than a brick chimney of equal flue area does.

Self-sustaining chimneys are frequently lined with fire-brick, but more often with ordinary hard-burned red brick, which can receive the chimney gases at 600° to 700° without injury.

Some, however, simply line the chimney at the bottom where the flue enters it, and in such cases second-quality fire-brick answers the purpose very well.

The thickness of brick lining should nowhere be less than 4½ inches, and that in the upper portion of the chimney, and the thickness should be increased toward the bottom, adding 4½ inches every 30 or 40 feet.

The size of flue and thickness of lining being known (usually adding from 18 to 36 inches to the diameter of the chimney shell or tube), we may start with the design of the chimney.

For an example we will assume the case of a chimney with an outside diameter of 66 inches and 150 feet high.

Let the diameter of the chimney be called D.

Let the diameter of the bottom of bell-shaped base be called D_B.

The writer usually makes the height of the bell-base, or $h_B = 2D$, and the diameter of bottom of bell $D_B = 2D$, though 1½ times the diameter D is often used for both the height h_B, and diameter D_B.

The outlines of the bell-shaped base in vertical projection should be bounded by straight lines, as of a cone, to give the greatest strength, but the outlines are often made curved as in a pealing bell, making use of thicker sheets of steel to counteract the loss of strength due to the straight outline.

The base-plate, usually made of cast-iron, should be kept from 12 to 24 inches above the level of the ground, but in no case should a high brick pedestal be used, it being much more expensive, less pleasing architecturally than the low foundation, without possessing any advantage with regard to strength, and it occupies much more space on the ground.

The base-plate is usually made of cast iron from 1 inch

TABLE No. 10.

WEIGHTS OF CIRCULAR BOILER HEADS.

Diameter in inches.	THICKNESS IN INCHES.														
	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
16	7	11	14	18	22	25	29	...	...	...	...	...	...	...	...
17	8	12	16	20	24	28	33	...	...	...	...	...	...	...	...
18	9	14	18	23	27	32	36	...	...	...	...	...	...	...	...
19	10	15	20	25	30	36	42	...	...	...	...	...	...	...	...
20	11	17	23	28	34	39	45	...	...	...	...	...	...	...	...
21	12	19	25	31	37	43	50	...	...	...	...	...	...	...	...
22	14	20	27	34	41	48	55	...	...	...	...	...	...	...	...
23	15	22	30	37	45	52	60	...	...	...	...	...	...	...	...
24	16	24	32	41	49	57	65	...	...	...	...	...	...	...	...
25	18	26	35	44	53	62	70	...	...	...	...	...	...	...	...
26	19	29	38	47	57	67	76	...	...	...	...	...	...	...	...
27	21	31	41	51	62	72	82	...	...	...	...	...	...	...	...
28	22	33	44	55	66	77	88	...	...	...	...	...	...	...	...
29	24	36	47	59	71	83	95	...	...	...	...	...	...	...	...
30	25	38	51	63	76	89	101	...	...	...	...	...	...	...	...
31	27	41	54	68	81	95	108	...	...	...	...	...	...	...	...
32	29	43	58	72	86	101	115	...	...	...	...	...	...	...	...
33	31	46	61	76	92	108	122	...	...	...	...	...	...	...	...
34	33	49	65	81	98	114	130	...	...	...	...	...	...	...	...
35	35	52	69	86	103	121	138	...	...	...	...	...	...	...	...
36	37	55	73	91	109	128	146	162	178	194	210	...	...	...	...
37	39	58	77	96	116	136	154	172	190	207	225	...	...	...	...
38	41	61	81	102	123	142	163	182	201	220	239	...	...	...	...
39	43	64	86	107	128	150	171	193	213	233	254	...	...	...	...
40	45	68	90	113	135	158	180	203	225	247	269	...	...	...	...
41	47	71	95	118	142	166	189	213	237	259	283	...	...	...	...
42	50	75	99	124	149	174	199	223	248	272	297	...	...	...	...
43	52	78	104	130	156	182	208	234	260	286	313	...	...	...	...
44	55	82	109	136	164	191	218	245	273	301	329	...	...	...	...
45	57	86	114	143	171	200	228	257	285	315	344	...	...	...	...
46	60	89	119	149	179	209	239	268	299	328	358	...	...	...	...
47	62	93	124	156	187	218	249	280	311	343	374	...	...	...	...
48	65	97	130	162	195	227	259	292	324	357	390	...	...	...	...
49	68	101	135	169	203	237	270	304	338	372	406	...	...	...	...
50	...	106	141	176	211	246	281	317	352	387	422	...	...	...	...
51	...	110	147	183	220	256	293	330	366	403	439	...	...	...	...
52	...	114	152	190	228	266	304	343	381	419	457	...	...	...	...
53	...	119	158	198	237	277	316	356	395	435	474	...	...	...	...
54	...	123	164	205	246	287	328	369	410	451	492	...	...	...	...
55	...	128	170	213	255	298	341	383	426	468	511	...	...	...	...
56	...	132	177	221	265	309	353	397	441	485	530	...	...	...	...
57	...	137	183	229	274	320	366	412	457	503	549	...	...	...	...
58	...	142	189	237	284	331	379	426	473	521	568	...	...	...	...
59	...	147	196	245	294	343	392	441	490	539	588	...	...	...	...
60	...	...	204	254	305	356	408	457	510	561	612	...	...	...	...
61	...	...	212	264	317	370	423	476	529	582	635	...	...	...	...
62	...	...	219	273	328	382	437	492	546	601	656	...	...	...	...
63	...	...	226	282	338	395	451	508	564	620	677	...	...	...	...
64	...	...	233	291	349	407	466	524	582	640	699	...	...	...	...
65	...	...	240	300	360	420	480	540	600	661	721	...	...	...	...

66	......	......	......	248	310	371	433	495	557	619	681	743	......	......	......	......
67	......	......	......	255	319	383	447	510	574	638	702	760	......	......	......	......
68	......	......	......	263	329	394	460	526	591	657	723	789	......	......	......	......
69	......	......	......	271	338	406	474	541	609	677	744	812	......	......	......	......
70	......	......	......	279	348	418	487	557	627	696	766	836	......	......	......	......
71	......	......	......	287	358	430	502	573	645	717	788	860	......	......	......	......
72	......	......	......	295	368	442	516	589	663	737	810	884	......	......	......	......
73	......	......	......	303	379	454	530	606	682	757	833	909	......	......	......	......
74	......	......	......	311	389	467	545	623	700	778	856	934	......	......	......	......
75	......	......	......	320	400	480	560	640	719	799	879	959	......	......	......	......
76	......	......	......	328	410	492	575	657	739	821	903	985	1067	1149	1231	1318
77	......	......	......	337	421	506	590	674	758	843	927	1011	1096	1180	1234	1348
78	......	......	......	346	432	519	605	692	778	865	951	1038	1124	1210	1297	1383
79	......	......	......	355	443	532	621	710	798	887	976	1064	1153	1242	1320	1419
80	......	......	......	367	458	550	641	733	830	917	1008	1100	1192	1283	1384	1476
81	......	......	......	378	473	568	662	757	851	946	1041	1135	1230	1324	1419	1514
82	......	......	......	388	485	582	679	776	872	969	1066	1163	1260	1357	1454	1551
83	......	......	......	397	497	596	695	795	894	993	1093	1192	1291	1390	1490	1589
84	......	......	......	407	509	610	712	814	916	1017	1119	1221	1322	1424	1526	1628
85	......	......	......	417	521	625	729	833	937	1042	1146	1250	1354	1458	1562	1667
86	......	......	......	427	533	640	746	853	960	1066	1173	1280	1386	1493	1599	1706
87	......	......	......	437	546	655	764	873	982	1091	1200	1309	1419	1528	1637	1746
88	......	......	......	447	558	670	782	893	1005	1117	1228	1340	1452	1563	1675	1787
89	......	......	......	457	571	685	779	914	1028	1142	1256	1370	1485	1599	1712	1827
90	......	......	......	467	584	701	817	934	1051	1168	1285	1401	1518	1635	1752	1869
91	......	......	......	......	597	716	836	955	1075	1194	1318	1433	1552	1671	1791	1910
92	......	......	......	......	610	732	854	976	1098	1220	1342	1463	1586	1708	1830	1953
93	......	......	......	......	623	748	873	998	1122	1247	1372	1496	1631	1746	1870	1995
94	......	......	......	......	637	764	892	1019	1146	1274	1401	1529	1656	1783	1911	2038
95	......	......	......	......	651	781	911	1041	1171	1301	1431	1561	1692	1822	1952	2082
96	......	......	......	......	664	797	930	1063	1196	1329	1462	1594	1727	1860	1993	2126
97	......	......	......	......	678	814	950	1085	1221	1357	1492	1628	1764	1899	2035	2171
98	......	......	......	......	692	831	969	1108	1246	1384	1533	1662	1800	1939	2077	2215
99	......	......	......	......	707	848	989	1130	1272	1413	1554	1696	1837	1978	2120	2261
100	......	......	......	......	721	865	1009	1153	1297	1442	1585	1730	1874	2018	2163	2307
101	......	......	......	......	735	882	1029	1175	1322	1470	1616	1764	1910	2058	2205	2352
102	......	......	......	......	750	899	1048	1197	1347	1498	1647	1798	1947	2098	2248	2398
103	......	......	......	......	764	916	1066	1219	1372	1525	1678	1832	1984	2138	2291	2444
104	......	......	......	......	779	933	1087	1241	1395	1551	1706	1862	2023	2178	2333	2488
105	......	......	......	......	794	950	1107	1263	1420	1577	1735	1894	2056	2215	2374	2533
106	......	......	......	......	808	967	1127	1286	1445	1605	1765	1926	2090	2254	2416	2578
107	......	......	......	......	822	984	1147	1309	1470	1632	1796	1960	2126	2298	2459	2624
108	......	......	......	......	836	1001	1166	1331	1496	1660	1827	1994	2162	2331	2499	2666
109	......	......	......	......	850	1018	1186	1354	1522	1689	1858	2027	2197	2369	2539	2710
110	......	......	......	......	865	1035	1205	1376	1547	1717	1888	2060	2232	2405	2580	2753
111	......	......	......	......	879	1052	1225	1398	1572	1745	1919	2094	2268	2443	2620	2795
112	......	......	......	......	894	1069	1245	1420	1596	1773	1950	2128	2306	2484	2663	2842
113	......	......	......	......	909	1086	1264	1442	1620	1880	1980	2162	2341	2522	2704	2886
114	......	......	......	......	923	1103	1284	1464	1645	1827	2010	2194	2377	2560	2745	2930
115	......	......	......	......	938	1120	1303	1486	1670	1855	2040	2226	2412	2598	2785	2992

Heads below heavy line will run heavier than the weight given.

TABLE No. 10.

WEIGHTS OF CIRCULAR BOILER HEADS.

Diameter in inches.	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
	THICKNESS IN INCHES.														
16	7	11	14	18	22	25	29	...	...	...	...	...	...	...	...
17	8	12	16	20	24	28	33	...	...	...	...	...	...	...	...
18	9	14	18	23	27	32	36	...	...	...	...	...	...	...	...
19	10	15	20	25	30	36	42	...	...	...	...	...	...	...	...
20	11	17	23	28	34	39	45	...	...	...	...	...	...	...	...
21	12	19	25	31	37	43	50	...	...	...	...	...	...	...	...
22	14	20	27	34	41	48	55	...	...	...	...	...	...	...	...
23	15	22	30	37	45	52	60	...	...	...	...	...	...	...	...
24	16	24	32	41	49	57	65	...	...	...	...	...	...	...	...
25	18	26	35	44	53	62	70	...	...	...	...	...	...	...	...
26	19	29	38	47	57	67	76	...	...	...	...	...	...	...	...
27	21	31	41	51	62	72	82	...	...	...	...	...	...	...	...
28	22	33	44	55	66	77	88	...	...	...	...	...	...	...	...
29	24	36	47	59	71	83	93	...	...	...	...	...	...	...	...
30	25	38	51	63	76	89	101	...	...	...	...	...	...	...	...
31	27	41	54	68	81	95	108	...	...	...	...	...	...	...	...
32	29	43	58	72	86	101	115	...	...	...	...	...	...	...	...
33	31	46	61	76	92	108	122	...	...	...	...	...	...	...	...
34	33	49	65	81	98	114	130	...	...	...	...	...	...	...	...
35	35	52	69	86	103	121	138	...	...	...	...	...	...	...	...
36	37	55	73	91	109	128	146	162	178	194	210	...	...	...	...
37	39	58	77	96	116	136	154	172	190	207	225	...	...	...	...
38	41	61	81	102	123	142	163	182	201	220	239	...	...	...	...
39	43	64	86	107	128	150	171	193	213	233	254	...	...	...	...
40	45	68	90	113	135	158	180	203	225	247	269	...	...	...	...
41	47	71	95	118	142	166	189	213	237	259	283	...	...	...	...
42	50	75	99	124	149	174	199	222	248	272	297	...	...	...	...
43	52	78	104	130	156	182	208	234	260	286	313	...	...	...	...
44	55	82	109	136	164	191	218	245	273	301	329	...	...	...	...
45	57	86	114	143	171	200	228	257	285	315	344	...	...	...	...
46	60	89	119	149	179	209	239	268	299	328	358	...	...	...	...
47	62	93	124	156	187	218	249	280	311	342	374	...	...	...	...
48	65	97	130	162	195	227	259	292	324	357	390	...	...	...	...
49	68	101	135	169	203	237	270	304	338	372	406	...	...	...	...
50	...	106	141	176	211	246	281	317	352	387	422	...	...	...	...
51	...	110	147	183	220	256	293	330	366	403	439	...	...	...	...
52	...	114	152	190	228	266	304	343	381	419	457	...	...	...	...
53	...	119	158	198	237	277	316	356	395	435	474	...	...	...	...
54	...	123	164	205	246	287	328	369	410	451	492	...	...	...	...
55	...	128	170	213	255	298	341	383	426	468	511	...	...	...	...
56	...	132	177	221	265	309	353	397	441	485	530	...	...	...	...
57	...	137	183	229	274	320	366	412	457	503	549	...	...	...	...
58	...	142	189	237	284	331	379	426	473	521	568	...	...	...	...
59	...	147	196	245	294	343	392	441	490	539	588	...	...	...	...
60	...	...	204	254	305	356	408	457	510	561	612	...	...	...	...
61	...	...	212	264	317	370	423	476	529	582	635	...	...	...	...
62	...	...	219	273	328	382	437	492	546	601	656	...	...	...	...
63	...	...	226	282	338	395	451	508	564	620	677	...	...	...	...
64	...	...	233	291	349	407	466	524	582	640	699	...	...	...	...
65	...	...	240	300	360	420	480	540	600	661	721	...	...	...	...

66				248	310	371	433	495	557	619	681	748				
67				255	319	383	447	510	574	638	702	760				
68				263	329	394	460	526	591	657	723	789				
69				271	338	406	474	541	609	677	744	812				
70				279	348	418	487	557	627	696	766	836				
71				287	358	430	502	573	645	717	788	860				
72				295	368	442	516	589	663	737	810	884				
73				303	379	454	530	606	682	757	833	909				
74				311	389	467	545	623	700	778	856	934				
75				320	400	480	560	640	719	799	879	959				
76				328	410	492	575	657	739	821	903	985	1067	1149	1231	1818
77				337	421	506	590	674	758	843	927	1011	1095	1180	1234	1848
78				346	432	519	605	692	778	865	951	1038	1124	1210	1297	1883
79				355	443	532	621	710	798	887	976	1064	1153	1242	1320	1419
80				367	458	550	641	733	830	917	1008	1100	1192	1283	1384	1476
81				378	473	568	662	757	851	946	1041	1135	1230	1324	1419	1514
82				388	485	582	679	776	872	969	1066	1168	1260	1357	1454	1551
83				397	497	596	695	795	894	993	1093	1192	1291	1390	1490	1589
84				407	509	610	712	814	916	1017	1119	1221	1322	1424	1526	1628
85				417	521	625	729	833	937	1042	1146	1250	1354	1458	1562	1667
86				427	533	640	746	853	960	1066	1173	1280	1386	1493	1599	1706
87				437	546	655	764	873	982	1091	1200	1309	1419	1528	1637	1746
88				447	558	670	782	893	1005	1117	1228	1340	1452	1563	1675	1787
89				457	571	685	779	914	1028	1142	1256	1370	1485	1599	1712	1827
90				467	584	701	817	934	1051	1168	1285	1401	1518	1635	1752	1869
91					597	716	836	955	1075	1194	1313	1433	1552	1671	1791	1910
92					610	732	854	976	1098	1220	1342	1463	1586	1708	1830	1958
93					623	748	873	998	1122	1247	1372	1496	1631	1746	1870	1995
94					637	764	892	1019	1146	1274	1401	1529	1656	1783	1911	2038
95					651	781	911	1041	1171	1301	1431	1561	1692	1822	1952	2082
96					664	797	930	1063	1196	1329	1462	1594	1727	1860	1993	2126
97					678	814	950	1085	1221	1357	1492	1628	1764	1899	2035	2171
98					692	831	969	1108	1246	1384	1533	1662	1800	1939	2077	2215
99					707	848	989	1130	1272	1413	1554	1696	1837	1978	2120	2261
100					721	865	1009	1153	1297	1442	1585	1730	1874	2018	2163	2307
101					735	882	1029	1175	1322	1470	1616	1764	1910	2058	2205	2352
102					750	899	1048	1197	1347	1498	1647	1798	1947	2098	2248	2398
103					764	916	1068	1219	1372	1525	1678	1832	1984	2138	2291	2444
104					779	933	1087	1241	1395	1551	1706	1862	2023	2178	2333	2488
105					794	950	1107	1263	1420	1577	1735	1894	2056	2215	2374	2533
106					808	967	1127	1286	1445	1605	1765	1926	2090	2254	2416	2578
107					822	984	1147	1309	1470	1632	1796	1960	2126	2293	2459	2624
108					836	1001	1166	1331	1496	1660	1827	1994	2162	2331	2499	2666
109					850	1018	1186	1354	1522	1689	1858	2027	2197	2369	2539	2710
110					865	1035	1205	1376	1547	1717	1888	2060	2232	2405	2580	2753
111					879	1052	1225	1398	1572	1745	1919	2094	2268	2443	2620	2795
112					894	1069	1245	1420	1596	1778	1950	2128	2306	2484	2663	2842
113					909	1086	1264	1442	1620	1880	1980	2162	2341	2522	2704	2886
114					923	1103	1284	1464	1645	1827	2010	2194	2377	2560	2745	2930
115					938	1120	1308	1486	1670	1855	2040	2226	2412	2598	2785	2992

Heads below heavy line will run heavier than the weight given.

thick for 100-foot chimneys to 3 inches thick for 250-foot chimneys, and from 16 inches to 36 inches larger than D_B in diameter for the above heights.

For the convenience of casting base-plates can be made in from two to six sections with flanges, held together by $\frac{3}{4}$-inch to $1\frac{1}{4}$-inch bolts, and need be solid only to within 12 inches inside the bell, that is, like a round wrought-iron washer.

Neglecting the flare at the base we will consider the whole height of a chimney with a common diameter D, and proceed to design the shell.

Considering the force of the wind as 50 pounds per square foot—the actual pressure on a cylinder is 50 per cent. of the above, or 25 pounds per square foot on the projected area. Add 5 pounds for compressive strain produced by the wind in one half of the shell and its dead load, and we have 30 pounds as a safe value for wind-pressure.

The height of the chimney under consideration, $H = 150$ feet, which, multiplied by $D = 5\frac{1}{2}$ feet and by 30 pounds, gives 24,750 pounds of wind-pressure distributed over the entire area.

The lever arm about the base being $\frac{H}{2}$, the bending moment is $24750 \times \frac{150}{2} = 185625$ foot pounds.

The section modulus, Z, for hollow cylinders is $\frac{\pi}{32}\left(\frac{D^4 - d^4}{D}\right)$, where $d =$ the inside diameter of the shell, and simplified the value of $Z = .0982\left(\frac{D^4 - d^4}{D}\right)$; having used feet before, feet should be used in this formulæ, or divide the results obtained from using inches by 12.

Dividing the bending moment obtained as above, by the section modulus Z, we obtain the strain per square inch on any section considered.

By calculating the bending moments at different heights of the chimney by multiplying the diameter by H by one-half of the height above the section under consideration by 30 pounds, we may then make use of the following table.

TABLE No. 20.

MOMENTS OF RESISTANCE OF THIN HOLLOW CYLINDRICAL BEAMS (IN FEET).

D = outside diameter. d = inside diameter. R in inches $= \dfrac{.0982\,(D^4 - d^4)}{D}$

Inside Diameter. Inches.	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
44	23.9	31.9	39.9	47.9	56.1	64.1	72.2	80.4
48	28.3	37.9	47.4	56.9	66.5	76.1	85.8	95.4
52	33.4	44.5	56.7	66.8	78.1	89.4	101.0	112.0
56	38.6	51.6	64.5	77.5	90.5	104.0	117.0	130.0
60	44.4	59.3	74.0	89.0	104.0	119.0	134.0	149.0
64	50.4	67.3	84.1	101.0	118.0	135.0	152.0	169.0
68	56.8	75.9	94.9	114.0	133.0	152.0	172.0	191.0
72	63.8	85.0	107.0	128.0	149.0	171.0	192.0	214.0
78	74.8	100.0	125.0	150.0	175.0	200.0	226.0	251.0
84	86.8	116.0	145.0	174.0	203.0	232.0	261.0	291.0
90	100.0	133.0	166.0	200.0	233.0	267.0	300.0	334 0
96	113.0	151.0	189.0	227.0	265.0	303.0	341.0	380.0
102	......	171.0	213.0	256.0	299 0	342.0	385.0	428 0
108	......	191.0	239.0	287.0	335.0	383.0	432.0	480.0
114	......	213.0	267.0	320.0	373.0	427.0	481.0	535.0
120	....	236.0	295.0	354.0	414.0	473.0	533.0	592.0
132	....	286.0	357.0	429.0	501.0	572.0	644.0	716.0
144	....	340.0	425.0	510.0	596.0	681.0	766.0	852.0
156	....	399.0	499.0	599.0	699.0	799.0	899.0	999.0
168	....	432.0	578.0	694.0	810.0	926.0	1043.0	1160.0
180	....	531.0	664.0	797.0	930.0	1064.0	1197.0	1331.0
192	....	604.0	755.0	906.0	1058.0	1209.0	1361.0	1513.0
204	....	682.0	853.0	1024.0	1194.0	1365.0	1536.0	1708.0
216	....	764.0	956.0	1147.0	1339.0	1530.0	1722.0	1914.0
228	....	852.0	1065.0	1278 0	1492.0	1705.0	1919.0	2133 0
240	......	943.0	1180.0	1416.0	1653.0	1889.0	2126.0	2362.0

(Power, 1897.)

Dividing above result by the strength in tension of steel-plate—45,000 to 50,000 pounds, divided by a factor of safety of 4, obtain the factor which in the horizontal line of chimney diameter will be found in the column of proper thickness of steel to be used for the shell at the section considered.

Thus for the chimney under consideration, 40 feet down from the top, we have $(5\frac{1}{2} \times 40)\,30 \times \frac{40}{2} = 132000$, which, divided by 12,000 pounds, gives 11 as the section modulus; so the shell may be made of less than $\frac{3}{16}''$ thickness at that elevation. It is not advisable to use less than $\frac{1}{8}''$ to $\frac{3}{16}''$ thickness of metal in any tall chimney, or short one, if long life is to be desired.

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= 15,320

The Philadelphia Engineering Works, Ltd., gives the following for the shells of steel chimneys:

TABLE No. 21.

SIR WILLIAM FAIRBAIRN'S EXPERIMENTS.

	Clear span.		Thickness iron.	Outside diameter.	Sectional area.	Breaking weight.	Breaking weight by Clark's formula. Constant 1.2 lbs.
	Feet.	Inches.	Inch.	Inches.	Square inches.	Lbs.	
I....	17	0	.037	12.0	1.3901	3,704	2,627
II....	15	$7\frac{1}{2}$	.113	12.4	4.3669	11,440	9,184*
III....	23	5	.0631	17.68	3.487	6,400	7,302
IV....	23	5	.119	18.18	6.74	14,240	13,910

Mr. Edwin Clarke has formulated a rule, from experiments conducted by him, in the use of iron and steel for hollow tube bridges, which is as follows:

$$(36)\quad \text{Centre breaking load in tons} = \left\{ \frac{\text{Area of material in inches.} \times \text{Mean depth in inches.} \times \text{Constant.}}{\text{Clear span in feet.}} \right.$$

When the constant used is 1.2, the calculation for the tubes experimented upon by Mr. Fairbairn are given in the làst column of the above table.

D. K. Clark's "Rules, Tables, and Data for Mechanical Engineers," page 513, gives the following rule for hollow tubes:

$$(37)\quad W = \frac{3.14D^2TS}{L}.$$

W = Breaking weight in pounds in centre.
D = Extreme diameter in inches.
T = Thickness in inches.
L = Length between supports in inches.
S = Ultimate tensile strength in pounds per square inch.

Taking S, the strength of a square inch of a riveted joint at 35,000 pounds, this rule figures as follows for the different examples experimented upon by Mr. Fairbairn:

I. $3.14 \times 144 \times 0.037 \times 35{,}000 \div 204 = 2{,}870$
II. $3.14 \times 153.76 \times 0.113 \times 35{,}000 \div 187.5 = 10{,}190$
III. $3.14 \times 312.5 \times 0.0631 \times 35{,}000 \div 282 = 7{,}700$
IV. $3.14 \times 330.5 \times 0.119 \times 35{,}000 \div 282 = 15{,}320$

ILLUS. No. 3.

HARTFORD STREET RAILWAY COMPANY'S CHIMNEY.

The Hartford Street Railway Co.'s (Hartford, Conn.) chimney is 166 feet high, diameter of bell at base 190 inches, tapering to 129 inches diameter at a height of 21 feet. Twenty-one feet of $\frac{1}{2}$-inch steel at bottom, 30 feet $\frac{7}{16}$-inch steel, 30 feet $\frac{3}{8}$-inch steel, 30 feet $\frac{5}{16}$-inch steel, and 55 feet $\frac{1}{4}$-inch steel at top. Ladder from top to within 2 feet of the base; a 5 by $\frac{1}{2}$-inch flat iron band around the top, on inside; copper cornice 190 inches diameter by 114 inches high, of 24-ounce copper; base plate 18 feet 6 inches square. This stack has $4\frac{1}{2}$ inches lining, thus making a 10 feet diameter flue.

A close approximation between the breaking weights obtained by his experiments and those derived from Mr. Edwin Clarke's and Mr. D. K. Clark's rules will be observed. It may be assumed, therefore, that this system of calculation is practically correct, and that it is eminently safe when a large factor of safety is provided, and from the fact that a chimney may be standing for many years without receiving anything like the strain taken as the basis of the calculation—fifty pounds per square foot. Wind pressure at fifty pounds per square foot may be assumed to be travelling in a horizontal direction and be of the same velocity at all points between the top and the bottom of the stack. This is the extreme assumption. If, however, the chimney is round, its effective area will be only half of its diametral plane, that is, the entire force on round chimneys if concentrated in the centre of the height of the section of the chimney to be considered.

Taking the average diameter of a 125-feet chimney as 90 inches, the effective surface in square feet upon which the force of the wind may act will, therefore, be 7½ times 125 divided by 2, which multiplied by 50, gives a total wind force of 23,437 pounds. The resistance of the chimney to breaking across the top of the foundation would be 3.14×168^2 (that is, diameter of base), multiplied by $.25 \times 35{,}000 \div (750 \times 4) = 258{,}486$, or 10.6 times the entire force of the wind. We multiply the half height above the joint in inches 750 by 4, because the chimney is considered a fixed beam with a load suspended at one end.

In calculating its strength half-way up, we have a beam of the same character, the beam in this case being fixed at a point half-way up the chimney, where it is 90 inches in diameter and .087 inch thick. Taking the diametral section above this point and the force as concentrated in the centre of it, or half-way up from the point under consideration, its breaking strength is: $3.14 \times 90^2 \times 0.187 \times 35{,}000 \div (381 \times 4) = 109{,}220$. The force of the wind to tear it apart through its cross-section at this line, $7\frac{1}{2} \times 62\frac{1}{2} \times 50 \div 2 = 11{,}725$, or a little more than one-tenth of the strength of the stack.

Riveting.—Not less than ½-inch rivets, and never a less diameter than the thickness of plate should be used.

For vertical or horizontal seams in flaring base the joints should be double-staggered riveting; above the bell a single riveted joint can usually be made use of, though for horizontal joints double-staggered riveted joint may often be most desirable and necessary—having a greater lap for sheet and consequently giving greater stiffness to the shell.

Button-head should invariably be used, with the button-head inside so as to present the least resistance to the gases.

Rivets should be spaced at least $2\frac{1}{2}$ times their diameter centre to centre, by a distance not any further apart than 16 times the thickness of the plate with which they connect; use all possible care to have the joint air tight and of sufficient strength.

In Reuleaux's "Constructor" is the following regarding riveted joints, which may be found of value in this connection.

Let s = thickness of plate.
d = diameter of rivet.
a = pitch of rivets, centre to centre of adjacent rivets.
n = number of rows of rivets.
ϕ = ratio of resistance of joint to full plate.
b' = overlap for shearing.
b'' = overlap for bending.

Overlap is the distance from centre of rivets to edge of plate.

In connection with the above we have the following table, No. 22, regarding lap-joints, which type is most frequently used in steel-chimney construction.

For ease of construction and economy also, the method of making the diameter of the circle between the plates the same for all joints is the best, and the upper end of each section should be placed inside the lower end of the section immediately above it. For brick-lined chimneys the reverse order is preferred.

In recent tests made of the flow of water under the direction of Clemens Herschel, of the East Jersey Water Company, of New York City, it has been found that the friction is appreciably less in pipes constructed as above over the style of one large course than one small one, and large one, etc.*

* Reference—One Hundred and Fifteen Experiments on the Flow of Water Through Riveted Pipes. Herschel. Published by John Wiley & Sons.

TABLE No. 22.

PROPORTIONS OF RIVETED JOINTS (REULEAUX'S "CONSTRUCTOR").

	$\frac{d}{t} =$	1.0		1.5		2.0		2.5		3.0		4.0	
	n	1	2	1	2	1	2	1	2	1	2	1	2
LAP JOINT.	$\frac{p}{t}$	1.63	2.22	2.92	4.33	4.52	7.04	6.43	10.47	8.67	14.33	14.07	24.14
	$\frac{b'}{t}$	0.39	0.39	0.88	0.88	1.57	1.57	2.54	2.54	3.53	3.53	6.28	6.28
	$\frac{b''}{t}$	1.06	1.06	1.78	1.78	2.58	2.58	3.46	3.46	4.31	4.31	6.48	6.48
	R	0.39	0.55	0.49	0.65	0.56	0.72	0.61	0.76	0.65	0.79	0.72	0.83
$\frac{\pi d}{5t} =$	$\frac{c}{s}$	0.63	0.63	0.94	0.94	1.26	1.26	1.57	1.57	1.88	1.88	2.51	2.51
BUTT JOINT.	$\frac{p}{t}$	2.26	3.52	4.33	7.15	7.04	12.05	10.37	18.21	14.33	25.61	24.14	44.21
	$\frac{b'}{t}$	0.79	0.79	0.96	0.96	3.14	3.14	4.91	4.91	7.07	7.07	12.56	12.56
	$\frac{b''}{t}$	1.29	1.29	2.20	2.20	3.24	3.24	4.37	4.37	5.60	5.60	8.32	8.32
	R	0.56	0.72	0.65	0.79	0.72	0.83	0.76	0.86	0.79	0.90	0.83	0.94
$\frac{2\pi d}{5t} =$	$\frac{c}{s}$	1.26	1.26	1.88	1.88	2.51	2.51	3.14	3.14	3.77	3.77	5.03	5.03

d = diameter of rivet.
t = thickness of plate.
n = number of rows of rivets.
p = centre to centre, or pitch of rivets.
b' = lap for shearing conditions.
b'' = lap for bending conditions.
s = stress in the punched plate.
R = ratio of resistance of joint to that of the full plate.
c = pressure of rivet on thickness of plate.

Wherever possible one section in height should be made of one sheet in circumference, and the author prefers to make the bell one sheet in height by 6, 8, or 12 sheets direction of the circumference; joints in the latter to be double-staggered riveted.

We have the following graphic representation of the rule just given for stability of chimneys:

If the chimney is blown to the position of the angle indicated, or until the line from centre of pressure passes through the third of the foundation, indicated by the arrow, we have, by summation of moments, about $M = O$ or zero.

$$(38) \quad (W_c + W_F)\frac{D_F}{3} = \text{wind-pressure}\left(\frac{h_c}{2} + h_F\right).$$

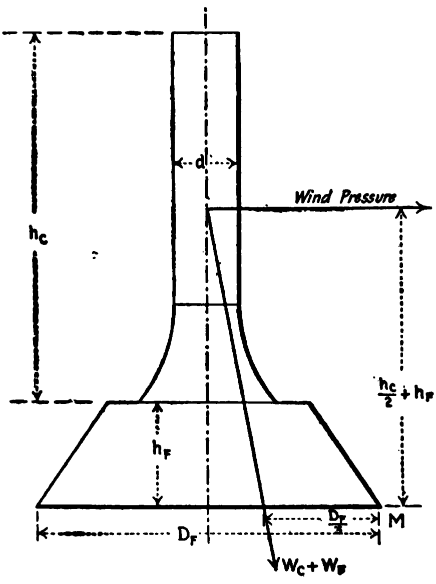
Collecting the data of a number of existing * self-sustaining steel chimneys and plotting the results given in the last three columns on the right in the accompanying table,† the author finds that a straight line fairly represents each mean, and for any chimney of steel—self-sustaining, the following equation holds good:

$$(39)\quad D_F = \frac{h_c^2 d}{26000} + 10.$$

Knowing h_c, h_F, which may be taken equal to or assumed a little less than D_F, W_c, D_F and wind-pressure, and substituting in equation, 38, we can obtain W_F for a given case.
By substitution:

$$(40)\quad (W_c + W_F)\frac{D_F}{3} = 30h_c h_F d + 15h_c^2 d.$$

Knowing the least diameter of the base of the foundation we can readily calculate the cubical contents of the necessary frustum of a cone by the following rule:



The contents of the frustum of a cone or pyramid are found by adding together the areas of the ends and the mean proportional between them (the square root of their product), and multiplying the sum by one-third of the perpendicular height.

In the event of the diameter of the base assumed for top and bottom of the foundation not giving enough weight, the size or area of base may be altered from round to hexagon, or square, or built up straight for 2 or 3 feet from bottom, or the weight increased in other ways—at the pleasure of the designer.

* Pp. 60, 61, 62. † Table 23, p. 60.

120 to 150 pounds per cubic foot is about the proper weight for such materials as enter into foundations of this character.

They should be made of any clean stone or brick-bats well grouted in Portland-cement mortar, thoroughly rammed.

The part out of the ground should be laid up with good-sized blocks of local quarry stone, rough dressed, or of brick.

The poorest soil will sustain about one ton load to the square foot of foundation area—quicksand not excepted, if it is properly covered over and confined.

Piling, however, is often resorted to in unstable bottoms, and along river-banks and in marshy lands.

Foundations.—The following is the rule for stability of steel chimneys and the relation to the foundation:

Find the total wind-pressure on the chimney and its moment about an axis in the plane of the base of the foundation.

Find also the total weight of the chimney with its lining, and of the foundation.

Divide the moment of the wind-pressure by the weight of the chimney and foundation; the quotient will be the distance from the outer edge at M which is the length of the lever-arm of the combined weights of foundation and chimney producing equality of moments.

Should this distance be $\frac{D_F}{2}$ then the chimney would be just stable; should this distance be less than $\frac{D_F}{2}$ then $\frac{D_F}{2}$ divided by the distance in question may be called a factor of stability, and consequently the less this distance becomes the greater is the factor of stability; this factor will never in any case become infinity (except in the case of no wind blowing), since no "chimney and its foundation" of given dimensions can have an infinite weight of material.

Therefore, the heavier the combined weight of the chimney and its foundation, the more stable the structure.

Should the distance above mentioned come within the outer third of the width of the foundation, the chimney is stable, with a fair factor of safety, provided of course that the chimney proper and its anchorage to the foundation have been properly designed and constructed.

The strength obtained from the ground to support the sides of the foundation, has been left out of our calculation, though the stability is increased by it. See p. 42.

For the chimney we have been considering, p. 50, using formula 38, we have:

$$(41) \quad 150 \times 30 \times 5\tfrac{1}{2} \times \left(\frac{150}{2} + 16\right) = 2252250 \text{ foot-pounds,}$$

where 16 feet is the depth of the foundation.

Weight of chimney is 38,000 pounds.
Weight of foundation is 400,000 pounds.

Total weight, 438,000 pounds, then $2252250 \div 438000 = 5.14$, which is less than $16 \div 3$, or 5.33, so the chimney is stable with a factor of stability of $8 \div 5.14 = 1.55$.

For foundations on loose soils it may be found desirable to increase the factor of stability to say $2\tfrac{1}{2}$ or 3.

If we had substituted the value of the wind moment about an axis in the plane of the base of the chimney, as obtained from equation 42, in place of the value obtained from 41, our result would show a still greater stability; this method, however, would not be strictly correct, as the depth of foundation, which in many cases is largely above ground, is left out of the consideration in equation 42.

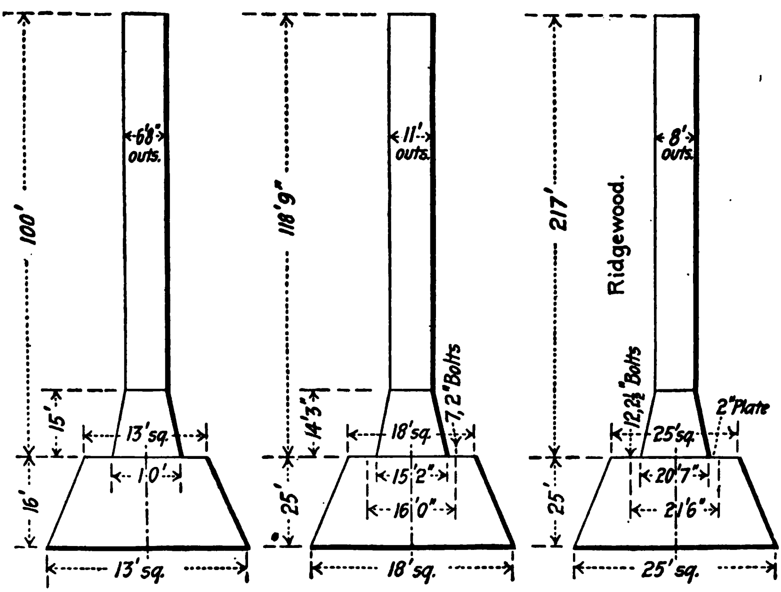
$$(42) \quad \text{Moment} = h_c \times 30 \times \frac{h_c d}{2} = 30\left(\frac{h_c^2}{2}\right) d.$$

Diameter at base of foundation $= D_F$.
Cubic feet of masonry in foundation $= C$.

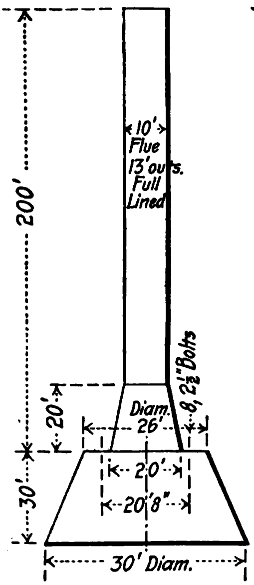
TABLE No. 23.

Chimney.	$\frac{h_c^2 d}{2}$	D_F	C	Foundation Depth.
No.		Feet.		Feet.
1...........	8,575	13 square	2,704	16
2...........	77,890	18 square	8,100	25
3...........	188,360	25 square	15,625	25
4...........	230,000	30 diameter	18,500	30
5...........	430,304	36 square	25,058	22
6...........	146,330	20 square	2,666	20
7...........	9,600	11¼ square	632	5
8...........	22,500	15 diameter	1,340	9
9...........	10,666	10½ square	707	9
10...........	9,600	13 diameter	676	8
11...........	348,046	47 diameter	27,566	22
12...........	188,180	30 diameter	6,961	13½
13...........	35,156	15 square	2,250	10
14...........	17,150	10 square	583	8

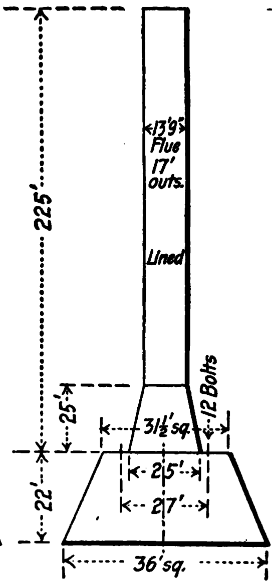
Anchorage.—To anchor the chimney to the foundation, bolts or rods are used running from a foot fastened to the bell of the chimney through the base-plate nearly to the bottom of the masonry, terminating in a lock-nut cast-iron washer.



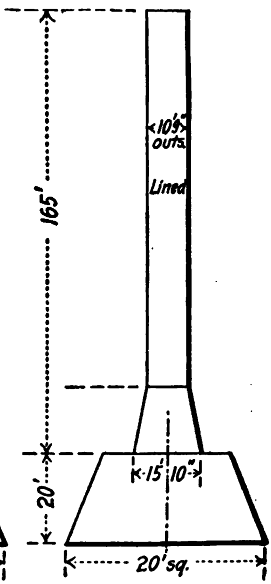
1. 2. 3.


200'
30'
20'
10'
Flue
13' outs.
Full
Lined
8, 2½" Bolts
Diam.
26'
20'
20'8"
30' Diam.

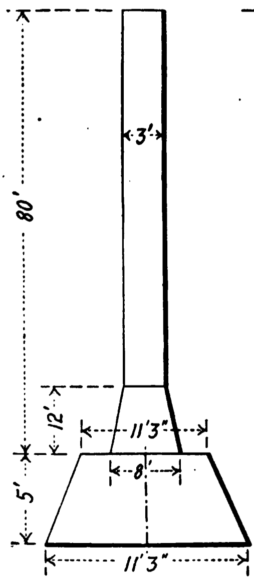
4.


225'
22'
25'
13'9"
Flue
17'
outs.
Lined
12 Bolts
31½' sq.
25'
27'
36' sq.

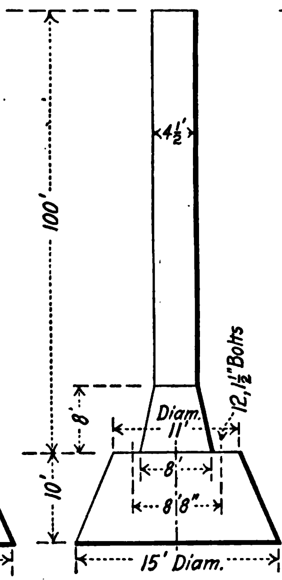
5.


165'
20'
10'9"
outs.
Lined
15'10"
20' sq.

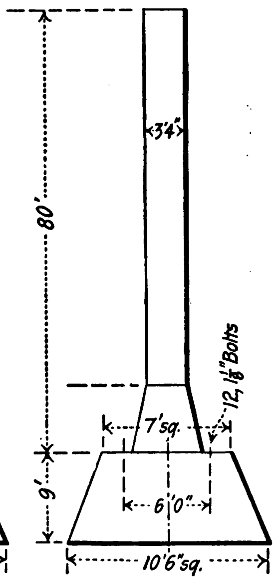
6.


80'
5'
12'
3'
11'3"
8'
11'3"

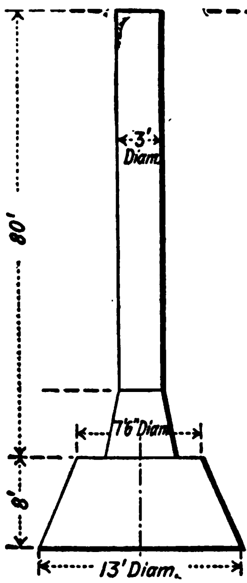
7.


100'
10'
8'
4½'
12, 1½" Bolts
Diam.
11'
8'
8'8"
15' Diam.

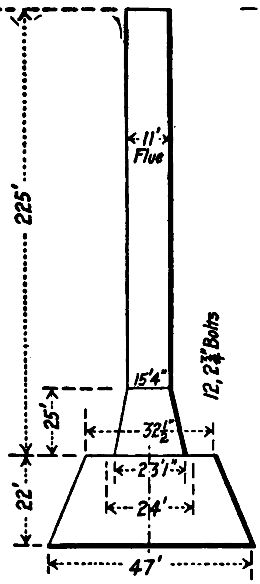
8.


80'
9'
3'4"
12, 1⅛" Bolts
7' sq.
6'0"
10'6" sq.

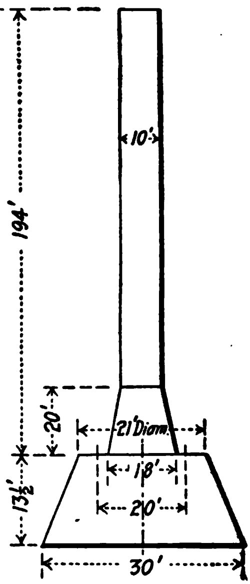
9.



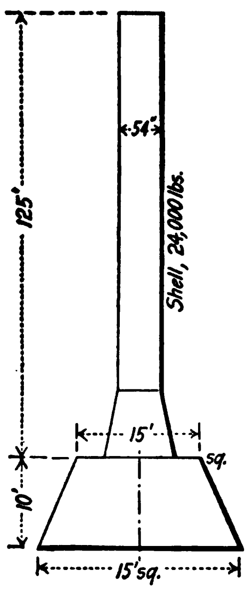
10.



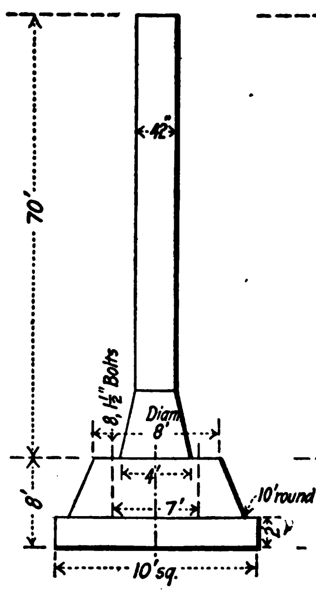
11.



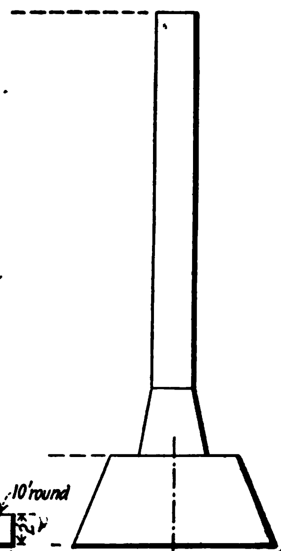
12.



13.



14.



15.

These anchor-bolts are both subjected to tension and shearing, but the chimney being not very likely to slide on its foundation, we neglect the shearing strain in our calculations.

As the lining of chimneys is not always in place or in good repair, we will neglect its weight, as it cannot be counted upon for assistance in keeping the chimney stable.

The overturning moment, M, is about the circumference of the largest diameter of the bell-base, or on a circle whose diameter is D_B and equals, $M = 25D_B\frac{H^2}{2}$. The weight of the steel shell being W, the moment of contrary effect to above, m is $m = W \times \frac{D_B}{2}$; which enables us to find the overturning moment $T = M - m$.

This is the moment on the foundation bolts, which are equally spaced in a circle, and are from 6 to 12 or even more in number, and the calculations for the bolts are made as follows:

Considering any point in the bolt circle, the approximate mean distance from the circumference of same on a line through the centre of the bolt circle to all of the bolts is the radius of that circle; and considering that one-half of the bolts only stand the strain, we have this equation:

$T_c = \frac{D_c}{2} \times$ tension on bolts $= \frac{D_c}{2} \times 9000$ pounds $\times$ number of bolts $\times$ area of one bolt.

Where $D_c =$ diameter of bolt circle,

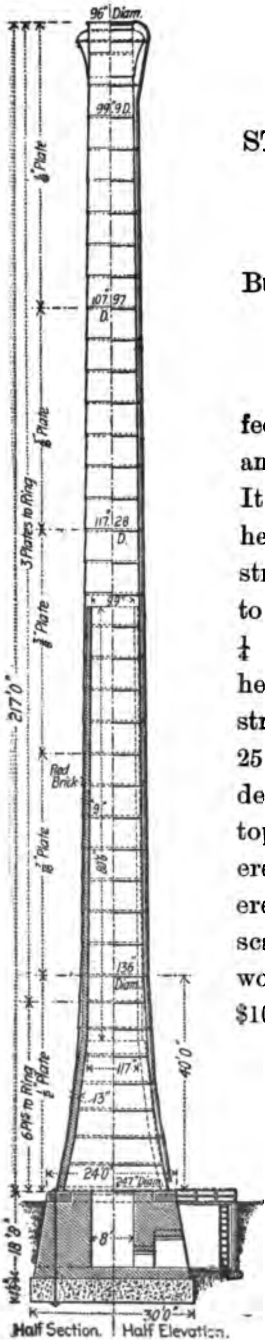
(43) $T_c = \left(T \times \frac{D_c}{2}\right) \div \frac{D_B}{2}$ or the moment on the foundation bolts.

For 6 foundation bolts, $T_c = 27000\ D_c \times$ area of one bolt.
For 12 foundation bolts, $T_c = 54000\ D_c \times$ area of one bolt.

In reality the mean distance of bolts from circumference in the half circle considered is $\frac{D_c}{2} + \frac{D_c}{6}$, and we are considerably inside the safe limit in the former assumption.

For the application to the chimney under consideration

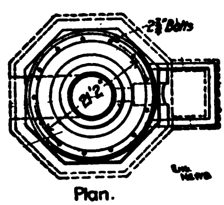
$$(44) \quad M = \frac{25 \times 5\frac{1}{2} \times 150 \times 150}{2} = 1546875.$$



STEEL CHIMNEY AT THE RIDGEWOOD PUMPING STATION, BROOKLYN, N. Y.

Built by the Philadelphia Engineering Works, Ltd., in 1896.

The height from the ground is 217 feet, the minimum diameter is 8 feef, and the diameter at the base is 25 feet. It is lined with brick for one-half of its height. There are 137 plates in the structure, varying in weight from 800 to 1,400 pounds, and in thickness from $\frac{1}{4}$ to $\frac{1}{2}$ inch. The plates are of open-hearth steel, of 65,000 pounds tensile strength, with an elongation of 20 to 25 per cent. in 8 inches. An iron ladder extends from the bottom to the top of the shell. The chimney was erected in ten weeks. The work of erecting was done from an inside scaffolding which was raised as the work progressed. The cost was about $10,000.



ILLUS. No. 4.

Let $W = 38000$ pounds assumed,

$$(45)\quad m = \frac{38000 \times 11}{2} = 209000,$$

$$T = M - m = 1546875 - 209000 = 1337875.$$

$$(46)\ \text{Let } D_c = 12\tfrac{1}{2}, \text{then } T_c = \frac{1337875 \times 6\frac{1}{4}}{5\frac{1}{2}} = 1520312.$$

(47) If 6 bolts are used, area of one bolt $= \dfrac{T_c}{27000 \times 12\frac{1}{2}} = 4.50$ square inches for present case.

(48) If 12 bolts are used, area of one bolt $= \dfrac{T_c}{54000 \times 12\frac{1}{2}} = 2.25$ square inches for present case.

Twelve bolts are the most convenient number to use, and if the base is made in 6 sections, 2 bolts will pass through each segment.

To ascertain the weight of the chimney, W, for the chimney being considered, the following thicknesses from the top down were used:

54 feet........ $\frac{3}{16}$ inch.	18 feet........ $\frac{3}{8}$ inch.
30 feet........ $\frac{1}{4}$ inch.	6 feet........ $\frac{1}{2}$ inch.
24 feet........ $\frac{5}{16}$ inch.	18 feet........ $\frac{5}{8}$ inch.

Base-ring.—The breadth of the base-ring can be readily determined by knowing the pressure on the base, but it is usually proportioned according to good practice, and with good judgment as accompanying conditions assist or compel.

STEEL CHIMNEY, GUYED, FOR AUGER & SIMON SILK DYEING COMPANY, PATERSON, N. J.

Flue 48 inches diameter by 125 feet high. Starting from the bottom with the foundation, which is 7 feet square at the bottom and 5 feet square at the top, 5 feet deep, 12 inches of which is out of the ground; the chimney rests on a cast-iron plate 5 feet square by $1\frac{1}{2}$ inches thick, having a rim 3 inches high inside of the shell of the chimney, this plate is held to the foundation by four $1\frac{1}{2}$-inch bolts 4 feet long.

The shell is made in sections 5 feet $4\frac{1}{2}$ inches in height of plate, 5 feet centre to centre of joints, each vertical section being made of one sheet.

The lower 65 feet of the chimney is $\frac{1}{4}$-inch thick steel; the upper 60 feet is $\frac{3}{16}$-inch steel; the chimney has an ornamental cap of simple design.

All joints are double staggered riveting, $2\frac{1}{2}$ inches centre to centre of rivets.

The upper end of each section is put in place inside the lower end of the section above it.

The chimney is supported by four guy-ropes of $\frac{3}{4}$-inch crucible-steel wire, six strands, 7 wires to each strand, laid about a hemp centre. These are strongly secured to the chimney at about 83 feet above its base and running from it to the ground, the ropes are made fast at about 80 feet from the base of the chimney to anchorages made of long pieces of 6-inch pipe placed in the ground at an angle of 45°, and the pipe has long timbers laid over it in the trenches to give large earth-bearing surface.

A turn-buckle is placed in each guy-rope for adjusting the tension of the same.

The chimney has stood well, and was erected in 1896.

A NOVEL WROUGHT-IRON CHIMNEY, CREUSOT, FRANCE.

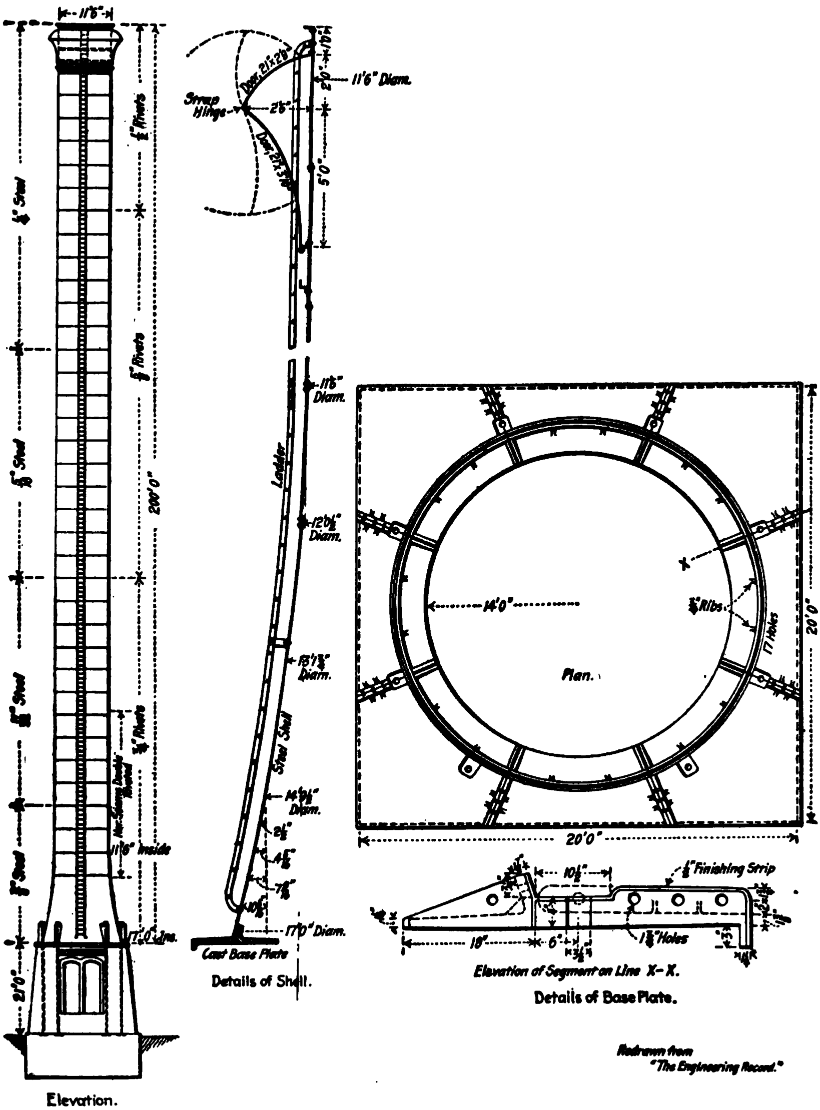
Total height, 279 feet; diameter at base, 23 feet; diameter at top, 7 feet 6 inches. Total weight, 80 tons, exclusive of masonry foundation. The latter is carried 3 feet 3 inches above the ground level and weighs about 300 tons.

The shaft is successive rings, each 4 feet 1 inch high. Thickness of sheets vary from $\frac{9}{16}$ inch at bottom to $\frac{1}{4}$ inch at top.

The nine lower rings have 8 plates in each, the upper ones 4 plates.

The base is encircled by a massive *angle-iron ring* bolted to the foundation.

Fire-brick lines the eight lower rings, or about 32 feet in height; seventy days were required for its erection including removal of scaffolding, which consisted of a 7-inch wrought-iron central tube provided with four cross arms of wood, made adjustable, resting on outer ends on plates, which arms carried the inner platform. The upper end of tube had four similar arms, from which was slung the exterior circular platform, which



ILLUS. No. 5.

A 200-FOOT STEEL CHIMNEY, WILMERDING, PA.

consisted of a pair of angle-iron rings to the outer edge of which was riveted a plate-iron fence, while the inner part was provided with T-iron stanchions.

Radial bearing timbers, resting on these rings, and adjustable endwise, to suit the varying diameters of the chimney, carried the plate, from an annular space left just sufficient for hoisting the plates.

The plates were hoisted by a rope passed over an adjustable pulley fixed to each jib in turn, and carried down a central tube to a snatch-block fixed at the bottom of the chimney.

The complete scaffold weighed about 4 tons, the heaviest plate about 800 pounds. Total cost of steel part of chimney and lining was about $8,000.—*Engineering News*, May 10, 1890.

Westinghouse Air Brake Co., at Wilmerding, Pa. Steel chimney, 200 feet high; built by Riter & Conley, Pittsburg, Pa.

The construction is shown very fully by the illustration on p. 67.

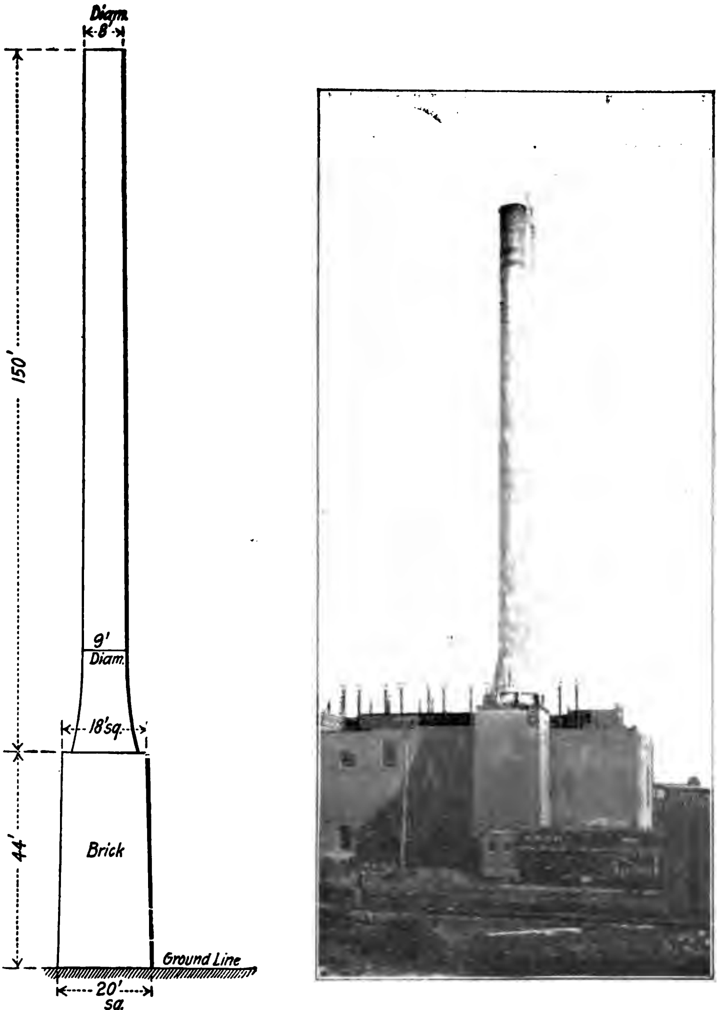
It was designed to resist a wind-pressure of 50 pounds to the square foot with a factor of safety of 4.

The material is punched and formed in the shops, and the principal riveting is done in the field.

The ladder was shipped in 15 or 20 foot lengths. The work was erected by using inside scaffolding, with a centre derrick for raising the sheets, and outside cages for the workmen which are hung on trolleys running on the edge of the shell.

These were raised by the derrick, as each course was added. When the chimney was finished it was painted from a swing carriage suspended from the trolleys which run on the Z bar underneath the top ornament.

Soot.—It is reported that soot $1\frac{1}{2}$ inches thick adheres to the interior of iron and steel chimneys.



ILLUS. No. 6.

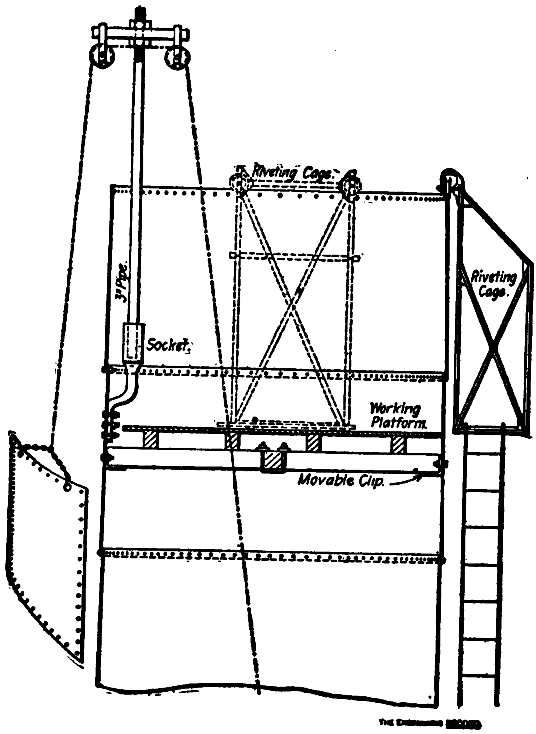
CHIMNEY OF THE REFRIGERATING PLANT OF THE ANHEUSER-BUSCH BREWING ASSOCIATION, ST. LOUIS, MO.

Steel Sheets.

Lower 50 ft.—⅝ inch thick.
Middle 50 ft.—½ inch thick.
Upper 50 ft.—⅜ inch thick.
The chimney is lined with fire-brick 125 feet up.

STEEL CHIMNEY ERECTION.

The Anheuser-Busch Brewing Association chimney, illustrated on the opposite page, was erected by ten men, who were carried by means of the light apparatus shown in this cut.



Four small angles bolted to the shell already in place, carried six-inch cross timbers, which carries the platform from which the men work.

Double-flanged wheels running on the top of the sheet-metal of the shell carried two light cages holding the riveters on the outside.

SELF-SUSTAINING STEEL CHIMNEY.

In the design of bases for the chimneys of this type, bell shapes are not strictly adhered to, in some cases, steel cables containing turn-buckles are secured to a straight steel tube at the height of say three diameters of the flue, and secured to the bottom anchor-bolts as usually located for bell bases.

In other cases two angle-irons riveted with thin separators are placed where the wire cable is located as above.

Still another method is very clearly illustrated in the cut on page 75; this chimney is 164 feet high.

Still another type of base is that shown in cut of Anheuser-Busch Brewing Association chimney on opposite page, being a square hollow-brick shaft.

Ladders.—Ladders are placed either within or without unlined chimneys, but always outside of lined chimneys.

Ornamental Caps.—Ornamental caps, as in the chimneys illustrated, are best made of copper, as they are then lighter and do not rust away as quickly as steel or iron caps, but they are expensive.

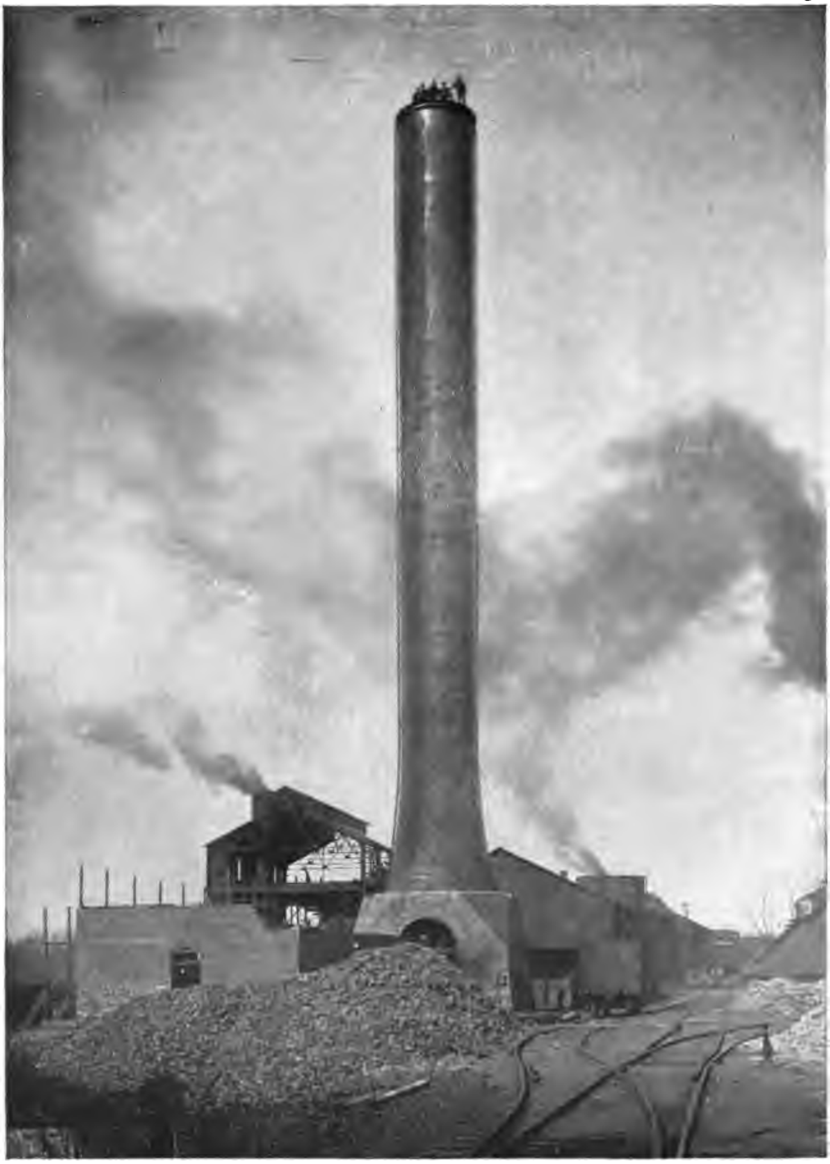
Ornamentation near the top of steel chimneys, at its best, is a poor investment, and very unsatisfactory, both architecturally and otherwise.

Painting.—Red-lead ground in linseed-oil, graphite paint, or the best quality of black asphaltum varnish should be used; two coats both inside and out should be given at erection, and one coat outside every year or two thereafter, for the proper protection against rust, etc.

Illus. No. 8 illustrates the general style of self-sustaining steel chimneys in and about Philadelphia, Pa. The following data pertain to chimneys of this style at that place:

A chimney 165 feet high, would be 15 feet 10 inches in diameter at the bottom of the bell, tapering to 10 feet 9 inches diameter in the straight part. Foundation would be a 20-foot cube.

A chimney 100 feet high would be 10 feet in diameter at the bottom of the bell, tapering to 6 feet 8 inches in diameter at a height of 15 feet from the base. In first 20 feet up from foundation of $\frac{3}{8}$-inch steel; the next 30 feet up, $\frac{5}{16}$-inch steel, and the



ILLUS. No. 7.

GUGGENHEIM SMELTING COMPANY, PERTH AMBOY, N. J.

upper 50 feet of $\frac{1}{4}$-inch steel. The foundation would be 16 feet high by 13 feet square.

Chimneys 100 feet high or less, are usually lined with red brick only to the top of the bell.

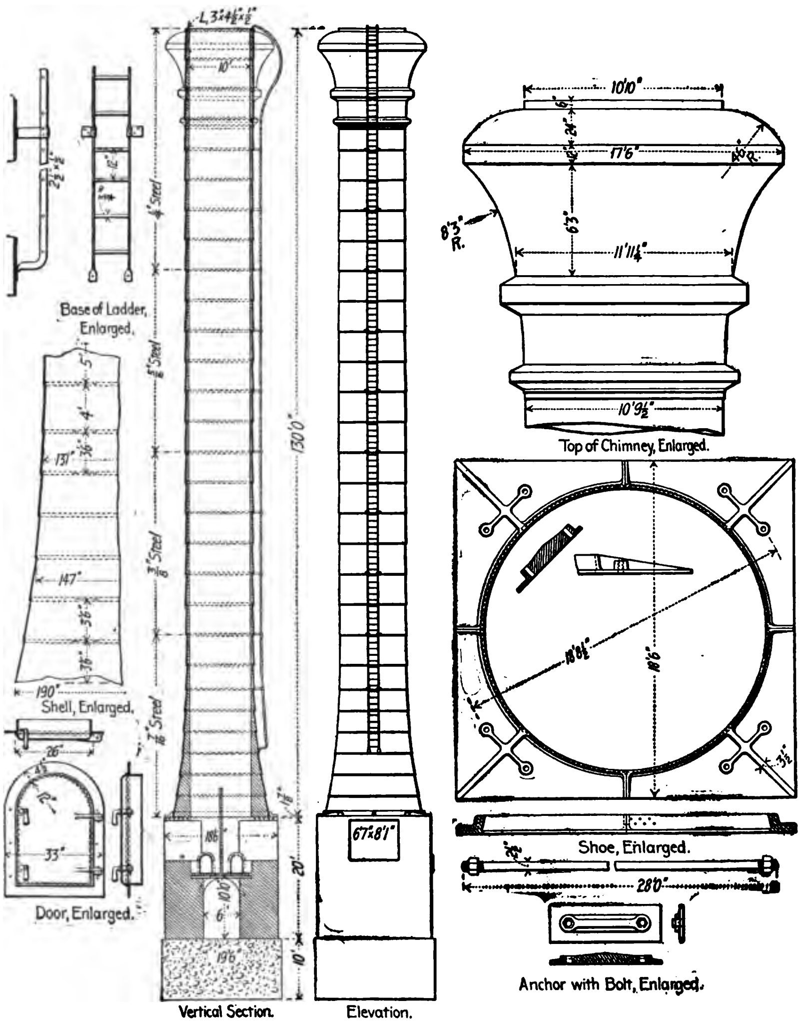
Angle-iron is often substituted at the top of the copper-moulded cap shown.

The bell is usually made in five rings of sheets 3 feet wide plus the lap, or 15 feet high altogether; the sheets above this being 5 feet or 6 feet wide plus the lap.

Ladders are put on chimneys over 100 feet high; under that height steel cable is placed over a pulley at the top, coming nearly to the ground so as to be used in hoisting a man to the top when it is necessary for painting or repair.

Chimney at the Guggenheim Smelting Company's Works, Perth Amboy, N. J., was 140 feet high, diameter at base 10 feet 6 inches, tapering in a height of 25 feet to 13 feet 6 inches diameter. Shell 35 feet of $\frac{7}{16}$-inch steel at bottom, 35 feet $\frac{3}{8}$-inch steel, 35 feet $\frac{5}{16}$-inch steel, and 35 feet of $\frac{1}{4}$-inch steel at top. Chimney has a 3 x 5 x $\frac{7}{16}$-inch angle band around the top; also a **Z** iron band; ladder the entire height; base plate 23 feet 11 inches diameter. This stack has 9-inch brick lining, thus making a 12-foot diameter flue.

This chimney was built in 1898 by the Coatesville Boiler Works.



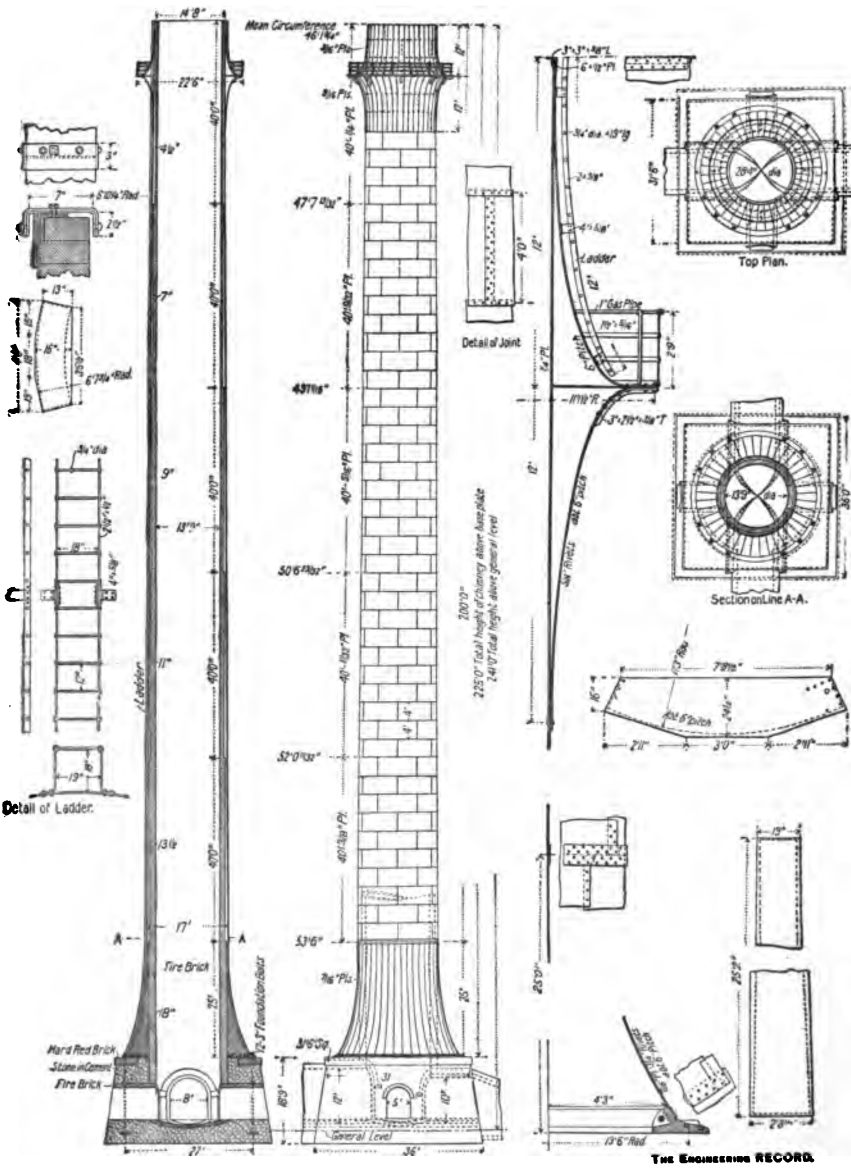
ILLUS. No. 8.

STEEL CHIMNEY AS USED IN AND ABOUT PHILADELPHIA, PA.

DESIGN AND CONSTRUCTION OF TALL STEEL STACKS.

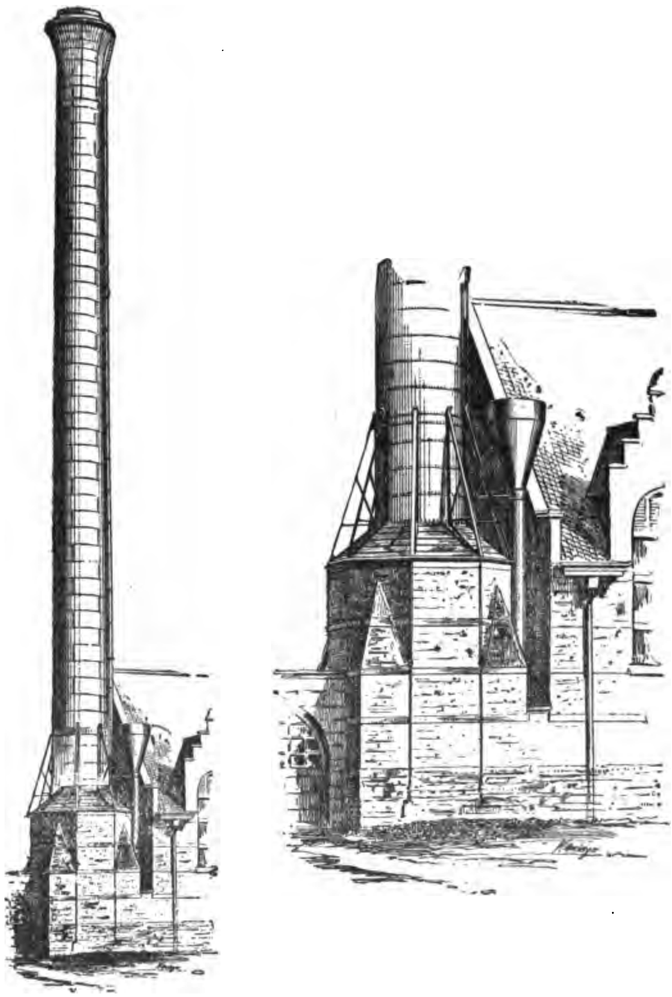
When the large blast-furnace plant of the Maryland Steel Company, at Sparrow's Point, Md., was designed it was deemed advantageous to operate the eight 22 x 75-foot Whitwell blast stoves, and the eight batteries of Babcock & Wilcox water-tube boilers, aggregating 2,000 horse-powers, serving each pair of furnaces by means of one brick-lined steel chimney. Two such chimneys were constructed of 13 feet 9 inches internal diameter and 225 feet in height. Set upon masonry about 16 feet above the surface of the ground, and standing in an exposed situation, independent of guys or bracing. The weight of the metal in each stack is about 77 tons, of the brick about 900 tons, and of the masonry pedestal and foundations about 1,600 tons, making a total of about 2,600 tons, as against 7,400 tons, which a structure of the same height and internal diameter is estimated to weigh if made entirely of brick, stone, and concrete.

The soil on which the chimney was constructed consisted of compact clay, which was excavated to a depth of 6 feet. The first course of stone was laid dry immediately on the clay. No piling was resorted to, and the foundation was built of good masonry in courses to a height of 16 feet above ground level. The base of the stack was made 40 feet square. The load per square foot of foundation area was thus 1.62 tons, and no settlement or irregularity has yet been observed. The masonry was large dimensioned stone, quarry-faced, with dressed arrises, set in a mortar of 1 Portland cement and 3 sand. The inside of smoke tunnels and the shaft was lined with brick offset to form walls of diminishing thickness, decreasing every 40 feet in height by one ring of brick, or in all from seven to two rings of brick.—See Kent, p. 741, for further description.



ILLUS. No. 9.

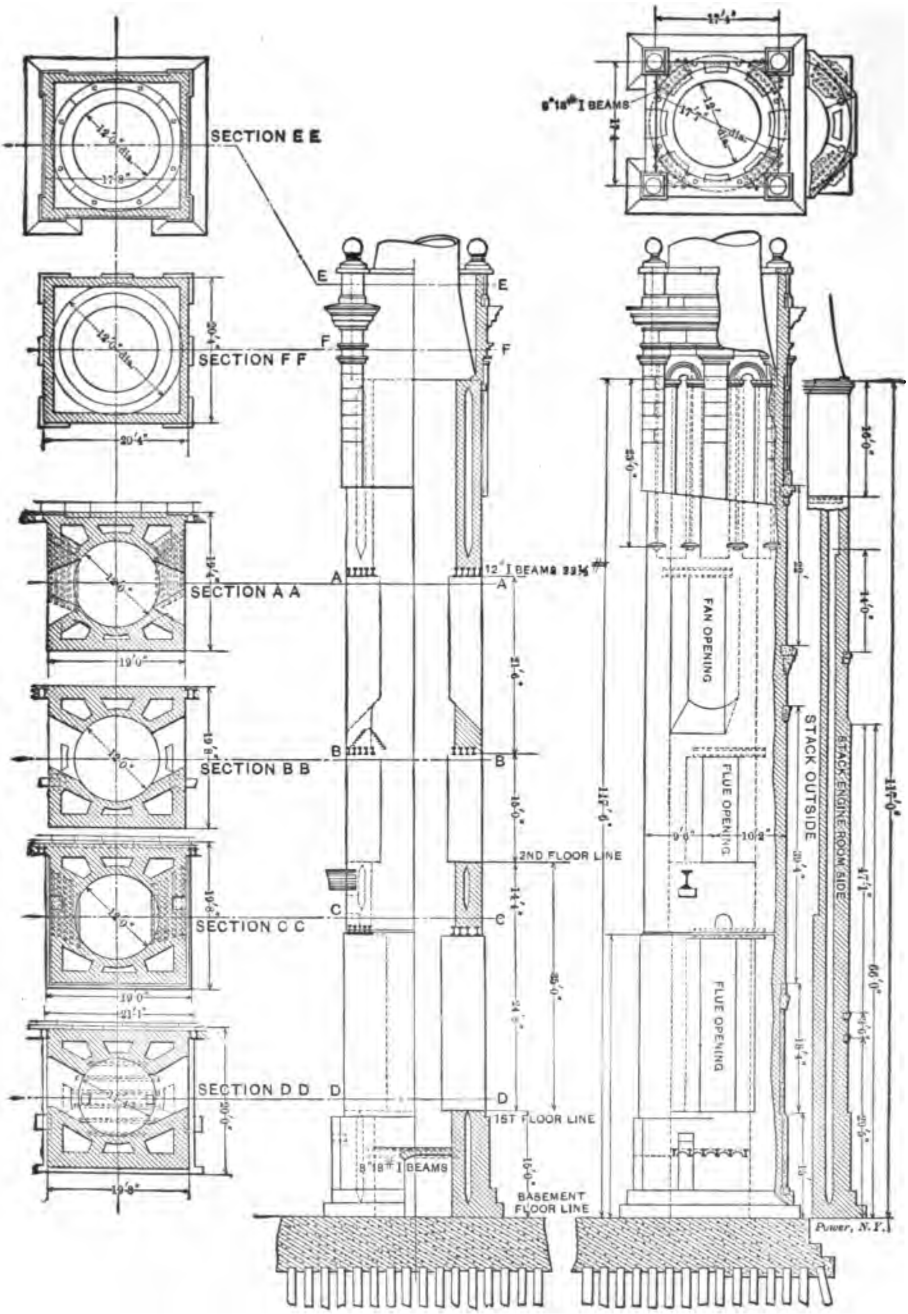
STEEL CHIMNEY, MARYLAND STEEL COMPANY.



ILLUS. No. 10.

Steel Chimney, Electric Light and Power Co., Garfield Park, Chicago, Ill.

Flue, —— diam. by 164 feet high.



ILLUS. No. 12.
Details of Chimney for Third Avenue Station, New York City.

ILLUS. No. 11.

SELF-SUSTAINING STEEL CHIMNEY (WOOLSON).

Dimensions.—54 inches diameter x 85 feet above foundation, 100 feet from ground.

The chimneys, of which there are to be four, will be constructed of brick to a point 102 feet above the lower boiler-room floor, and extended 98 feet higher by self-supporting steel stacks, making the height of the complete stack 200 feet. The brick portion is to be built into the building and treated as part of such, and is shown in section in illustration No. 12. The internal diameter is 12 feet. The lower section of the steel portion will be belled to 17 feet in diameter, the body diameter being 12 feet 9 inches, and be mounted upon a heavy cast-iron stack-plate 18 feet 8 inches in diameter. Eight steel brackets 24 inches in height will be riveted to the first ring to take the anchor-bolts.

The entire chimney is to be lined with ordinary brick laid in lime mortar rendered hydraulic with Portland cement. The top is to have a locomotive type ornament of copper and a Z-bar painting ring. A steel ladder will run up the outside and over the top of each stack.

The rated boiler horse-power of this station is 31,200, or 2.09 square inches of chimney-flue area per boiler horse-power.

The Metropolitan station has a single chimney of 22 feet diameter for a rated boiler capacity of 21,700 horse-power, or about 2.5 square inches per horse-power. The four chimneys of 12 feet diameter are equivalent to one of 24 feet diameter for a rated capacity of 31,200 horse-power, or about 2.09 square inches per horse-power.

The Metropolitan chimney * is, moreover, 353 feet in height, against 200 for those of the station under consideration. Intensity of draft and increased capacity are obtained in the latter instance by fans, instead of by excessive chimney height, two fans, each capable of handling the gases from 4,000 horse-power of boilers, being attached to each chimney.

These fans are to be capable of producing a draft equivalent to that of a stack 500 feet in height. They are to be overhung in heavy steel-plate housings, the main bearings are to be water-jacketed, and each fan is to be provided with a large sliding damper, by means of which it may be isolated from the hot gases when not in use.—*Power*.

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* See p. 123.

The Pueblo, Col., chimney, p. 00, is made of the following weights of steel plates, beginning from the top down:

30 feet of 10 pounds per square foot, $\frac{1}{4}$ inch thick.
25 feet of 13 pounds per square foot, $\frac{5}{16}$+ inch thick.
25 feet of 15 pounds per square foot, $\frac{3}{8}$ inch thick, scant.
25 feet of 18 pounds per square foot, $\frac{7}{16}$+ inch thick.
25 feet of 20 pounds per square foot, $\frac{1}{2}$ inch thick, scant.

Diameter of main shell 13 feet 8 inches, enlarging at the bottom to 19½ feet diameter, with an inch of sand between the shell and brick lining, which lining extends throughout the chimney, leaving a flue 12 feet in diameter from the concrete sub-base upward.

The concrete sub-base is 30 feet square by 12 feet deep.

The brick frustum of a cone 28 feet square at the bottom, 25 feet square at the top, by 20 feet high.

Flue door 7 feet wide by 16 feet high.

The approximate costs are as follows:

Steel shell erected	$7,000
Brick lining	1,400
Foundation and pedestal masonry	3,600
Total cost	$12,000

Built by the Coatesville Boiler Works.

W. W. C's rating of this chimney is 4,186 horse-power.

Following this, we have a list of steel chimneys on page 79.

1. Pennsylvania Railroad Company, at Jersey City, N. J., built 1892.
   Base-plate, cast iron.
   Flue, 4 feet 8 inches in diameter by 125 feet high.
   Upper half of shell, $\frac{1}{4}$-inch steel.
   Lower half of shell, $\frac{5}{16}$-inch steel, except bottom sheet of $\frac{3}{8}$-inch steel.
   Diameter outside at bottom, 12 feet 6 inches.
   Diameter outside at top, 6 feet 10 inches.
   Lined throughout with 12 inches of brickwork.
   Vertical seams—rivets, $\frac{5}{8}$-inch diameter, 3-inch pitch.
   Horizontal seams—rivets, $\frac{5}{8}$-inch diameter, $3\frac{1}{2}$-inch pitch.
2. Cleveland Electric Illuminating Company, Cleveland, O.
   Lined chimney, 11 feet 6 inches diameter by 225 feet high.
   (See *Engineering Record*, vol. xxxv., p. 386.)
3. Westinghouse Air Brake Company, Wilmerding, Pa.
   Flue, 11 feet 6 inches diameter by 200 feet high. (See description and cut, pp. 67 and 68.)
4. Bronx Company, Bronxville, N. Y.
   Flue, 4 feet 6 inches diameter by 100 feet high.
5. Hartford Street Railway Company, Hartford, Conn., and
6. Manhattan Street Railway Company, Brooklyn, N. Y.
   Height, 165 feet.
   Diameter at top, 10 feet 9 inches.
   Diameter at bottom of bell, 15 feet 10 inches, tapering to 10 feet 9 inches in straight part of chimney.
   The foundation is a 20-foot cube.
7. Burden Iron Company, Troy, N. Y.
   6 feet 3 inches diameter; 150 feet high.
8. Ridgewood Pumping Station, Brooklyn, N. Y.
   8 feet diameter by 217 feet high. (See description and cut, p. 64.)
9. Potomac Light and Power Company, Washington, D. C.
   9 feet diameter by 200 feet high.
10. City and Suburban Railway Company, Baltimore, Md.
   Two chimneys, 11 feet diameter by 118 feet 9 inches high. Two stacks are provided, one for each $2\frac{1}{2}$ batteries. These stacks are of steel plate, lined with fire-brick. The metal

stacks rest upon brick piers 18 feet square, of sufficient height (21 feet 6 inches above the boiler-room floor) to take in brick smoke-flues, thus avoiding any cutting of the metal stack, which is weakening and also an unsatisfactory detail to some designers.

The stacks are 11 feet in diameter by 118 feet 9 inches high above the top of the brick pier. The lower section of 14 feet 3 inches is cone-shaped, 15 feet 2 inches in diameter where it rests upon the brick pier. The base-plate is of heavy cast iron, anchored to the pier with seven 2-inch bolts each 24 feet 6 inches long, built into the pier with large anchor-washers; these bolts are up-set $2\frac{1}{2}$ inches for the nut.

The cone-shaped section is $\frac{5}{8}$ inch thick, and the heights of the other sections and the thickness of the steel are as follows: second, 15 feet, $\frac{9}{16}$ inch thick; third, 15 feet, $\frac{1}{2}$ inch thick; fourth, 15 feet, $\frac{7}{16}$ inch thick; fifth, 20 feet, $\frac{3}{8}$ inch thick; sixth, 20 feet, $\frac{5}{16}$ inch thick; balance, 33 feet 9 inches, $\frac{1}{4}$ inch thick. Around the top is riveted a heavy angle-iron stiffening.

11. Cleveland Rolling Mill, Cleveland, Ohio.

11 feet diameter by 190 feet high. (See description, p. 83.)

12. East Boston Electric Railway Power Station, Boston, Mass.

5 feet diameter of flue by 130 feet high.

Outlet for furnaces of 4 Corliss boilers with a total of 8,672 square feet of heating surface. (*Engineering Record*, November, 1894.)

13. Creusot, France.

7 feet 6 inches diameter by 279 feet high. (See description, p. 60, *Engineering News*, May 10, 1890.)

14. Maryland Steel Company, Sparrow's Point, Md.

13 feet 9 inches diameter by 225 feet high. (See description and cut, pp. 73 and 74.)

15. Hartman General Electric Company, Duluth, Minn.

7 feet 6 inches diameter by 200 feet high.

16. Etna Iron Works, Ironton, Ohio.

9 feet diameter by 200 feet high. (Built in 1874.)

17. East River Gas Company, Long Island City, N. Y.
6 feet diameter by 150 feet high.
18. United Glass Company, Chicago, Ill.
6 feet diameter by 125 feet high.
19. Aspinook Company, Jewett City, Conn.
6 feet diameter by 100 feet high.
20. Consolidated Gas Company of New Jersey, Long Branch, N. J.
Not lined; 5 feet diameter of flue by 130 feet high, built in 1896.
21. Consolidated Gas Company of New Jersey, Long Branch, N. J.
6 feet diameter of flue by 120 feet high, built in 1897.
22. Arnold Print Works, North Adams, Mass.
Built in 1896. 42 inches diameter by 100 feet high—guyed.
23. Arnold Print Works, North Adams. Mass.
60 inches diameter by 130 feet high—guyed.
24. Arnold Print Works, North Adams, Mass.
88 inches diameter by 128 feet high—guyed.

Of the latter the lower 23 feet is $\frac{3}{8}$-inch steel,
the next 50 feet is $\frac{5}{16}$-inch steel,
the upper 55 feet is $\frac{1}{4}$-inch steel.

Base-plate is of cast iron, 14 feet diameter, $2\frac{1}{2}$ inches thick, with a shoulder-ring $3\frac{1}{2}$ inches high by 2 inches thick to go inside of the chimney, and with rivets through same.

Total weight of chimney and base-plate, 22 tons.

Through the base-plate were eight $1\frac{1}{2}$-inch bolts for anchorage.

Each of these chimneys was erected in one piece. (*Power*, November, 1896.)

25. Darwin and Mostyn Iron Company.
Height above foundation, 260 feet.
Depth of foundation, 15 feet.
External diameter at base, 27 feet 6 inches; external diameter at top, 11 feet.
Weight of chimney with foundation, 1,100 tons; weight of equivalent brick chimney, 3,000 tons.

26. Kineshmia, Russia.
170 feet high.

27. Middlesborough, England.
165 feet high.

28. Gottfried Brewing Company, Chicago, Ill.
Outside diameter 9 feet 5 inches by 175 feet; lined.

Steel varies in thickness from $\frac{5}{32}$ inch at the top to $\frac{3}{8}$ inch at the bottom.

The lower 75 feet is lined with fire-brick 8 inches deep, formed to fit the shell; above this is a hollow-tile lining.

The lining is supported at intervals of 25 feet by an angle-iron riveted to the shell.

The foundation is one layer of cement, then two layers of steel rails in cement, then one layer of I-beams, on which the cast-iron base-plate rests.

This chimney furnishes draft to 12 boilers, 60 inches diameter by 20 feet long.

29. Straight-Line Engine Works, Syracuse, N. Y.
Unlined, of No. 10 iron, self-supporting; 79 feet high.

38 inches diameter at top, and 40 inches at bottom.

It has stood gales which demolished large trees, and is built with the top end of the first piece outside of the bottom end of the piece above. (*Power*, December, 1896.)

30. Toledo Traction Company, Toledo, Ohio.
Lined with fire-brick and tile; self-supporting.

Flue 13 feet inside diameter by 213 feet high.

Furnishes draft for four 300 horse-power Sterling boilers.

Furnishes draft for four 200 horse-power Heine boilers.

To run four 1,200 indicated horse-power Green-Wheelock engines.

Thirteen pounds steam per indicated horse-power is guaranteed. (*Electrical Engineer*, January 6, 1897.)

31. Schneider's, Creusot, France.
Top diameter, 27½ inches, by 98 feet 6 inches high.

London *Engineering*, p. 419, 1898, gives an illustration of these chimneys, or one of them being erected in one piece.

32. Dublin (Ireland) United Tramways Company.

2 steel-lined self-supporting chimneys, 10 feet diameter by 200 feet high, on brick bases, which are 26 feet high. Total height of chimney, 226 feet.

33. Metropolitan Street Railway Company, Kansas City, Mo.

Self-supporting steel chimney; flue, 8 feet 4 inches diameter by 175 feet high; shell, 10 feet 6 inches diameter. (*Engineering News*, April 8, 1897.)

34. Edison Lighting Station, New York City.

Two steel-lined chimneys.

Flue, 12 feet diameter by 139 feet high, from ceiling or base to top.

The upper 74 feet 9 inches is self-supporting, the cast-iron base of which is secured by eight 1⅛-inch anchor-bolts passing down 32 feet in wall.

The *Engineering Record*, vol. xxx., p. 44, contains a detail cut of these chimneys, showing a very ingenious expansion-joint, at the place where cast-iron cap above-mentioned is set.

35. Elevated Railroad Company, Chicago, Ill.

Self-supporting steel chimney.

Flue, 5 feet diameter by 120 feet high, lined.

To furnish draft to three 150 horse-power Heine boilers.

36. Cleveland Rolling Mill Company, Cleveland, Ohio. Engineers and constructors, Messrs. Witherow & Gorden, Pittsburg, Pa.; built September, 1881. About 50 days were occupied in its erection, apart from the building of the foundation proper.

Dimensions.—

Height, including foundations	213 feet 6 inches.
Height, from ground line to top	190 feet 0 inches.
Height of bell-shaped base	21 feet 0 inches.
Outside measurement of foundation	30 feet 6 inches.
Outside diameter at foot of bell-base	21 feet 2 inches.
Outside diameter at top of bell-base	13 feet 0 inches.
Outside diameter at top	12 feet 0 inches.
Internal diameter throughout	11 feet 0 inches.

Foundation.—Stone, laid in cement, and is situate in what is termed the "Bottom," next to Cuyahoga River, where the ground is all of alluvial formation. For such a load as this

chimney the foundation required close piling; the piles were driven 23 feet to 24 feet in depth, and almost in contact with each other; through the stone foundation eight 2½-inch bolts were passed, connecting a circular cast-iron foundation-plate of T-section, 18 inches by 8¼ inches at bottom of stonework, to similar casting upon the top of stone foundation; this top circular ring or base-plate is formed with a projecting flange placed at an angle of sixty degrees to receive plates forming bell-shaped base, 2 feet above ground.

Construction.—The chimney was constructed by inside scaffolding, and built up one plate high at a time; the workmen hanging what is called a "cage" on the plates, to serve as a stand for the "holder on" while riveting the plates *in situ.*

Bell-shaped Base.—The plates forming the base are bolted to the flange of chimney base-ring by ¾-inch bolts, and when completed to a height of 21 feet form a bell-shaped base 21 feet 2 inches diameter at bottom, and 13 feet 6 inches at top.

Shaft.—From the top of bell-shaped base the wrought-iron outer casing is continued to height of 21 feet from below top; from this point the cap is formed as shown in drawing.

Rivets and Riveting.—The plates are all riveted together with a lap of two inches; the constructors used conical-shaped rivet-heads, and the diameter of rivets for this class of work is as near as possible twice the thickness or upward of plate, and the pitch of rivets is 5 diameters.

Ladder.—A wrought-iron ladder is fixed to the outside.

Fire-brick Lining.—A fire-brick lining was built up through the entire height of the chimney, commencing at junction of flues at foundation with a thickness of 18 inches, and finishing at top 5 inches thick. The internal diameter, when finished with lining, is 11 feet, and constant throughout its height; the radiated fire-bricks were of five sizes, purposely made.

Stability.—The chimneys built on this plan are calculated to withstand 50 pounds wind-pressure per square foot with safety; the constructors say the climate of America is dry, and no doubt better for such structures than the climate of England; they believe that no one alive at the present time will see the end of a wrought-iron chimney, lined with brick; the oldest ones in America show no material deterioration. Cost, complete, $13,000.

CHAPTER VII

BRICK CHIMNEYS—THEORY PERTAINING TO SAME, AND EXAMPLES FROM EXISTING STRUCTURES

RULES FOR BRICK CHIMNEYS.

MOLESWORTH'S "Pocket Book" gives the following: "Diameter outside of the base, not less than one-tenth the height; batter of outside, 0.3 inch per foot; thickness of brickwork, one brick from top to 25 feet down; one and one-half brick from 25 feet to 50 feet, etc. If inside diameter exceeds 4 feet at the top, the top thickness should be one and one-half bricks; if less than three feet it may be one-half brick for the first 10 feet down."

The Metropolitan Board of Works Rules for furnace chimney shafts contain this: Brickwork should be at least 8½ inches thick at the top, and for 20 feet below, and must be increased 4½ inches every 20 feet of additional height measured downward. There should be no cornice or projection of more than 8½ inches at the top of the shaft.

Lang gives for thickness of upper wall of chimneys:

If built of ring stone, at least 7.08 inches.

If built of bricks, at least 9.84 inches.

For quadrangular chimneys, ½ brick thickness may be used in upper section, but the chimney must then be built from the exterior, and well braced by scaffolds.

The more steam there is contained in the smoke gases and the cooler they are, the larger the thickness of the upper wall should be chosen.

The old rule that the upper wall thickness should be $\frac{1}{10}$ of

the clear width given too thin walls for narrow chimneys, and too thick ones for wide chimneys.

Rather $S_1 = 0.10 + 0.05\ d_0 + 0.0005\ H$ (in metric system). Answer in meters

$S_1 = 3.937 + 0.05\ d_0 + 0.0005\ H$ (in United States measure). Answer in inches

S_1 = thickness, d_0 = clear inside diameter at top, H = height of chimney.

The author would advise making the lengths of each varying thickness 20 to 30 feet,* with an outside batter of 1 in 30 to 1 in 36, and also running the inner core to within a few feet of the top, but not to connect it with the outside shell; in all cases calculate each section for stability, which will also aid in determining the thickness of brickwork.

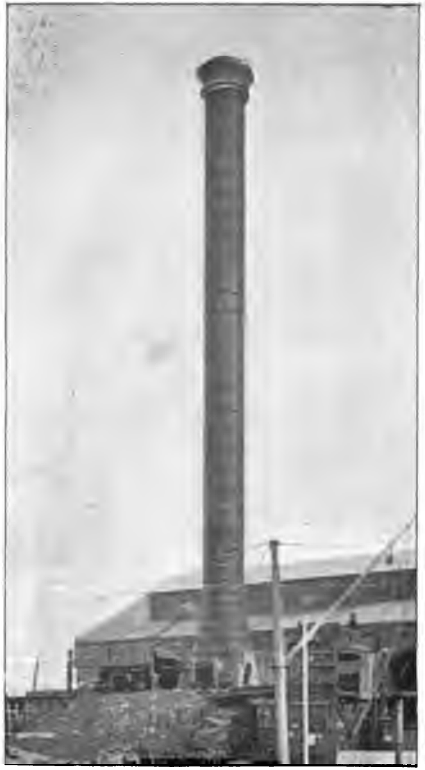
One authority suggests for a brick chimney 100 feet high, an outer shell in three steps, the first 20 feet, 16 inches thick; the second 30 feet, 12 inches thick; the third 50 feet, 8 inches thick—all minimum thicknesses; batter no less than 1 in 36 to give stability. The core should be in three steps of equal height, 12, 8, and 4 inches thick.

Brick chimneys should not be connected in a structural manner with any other structure, owing to both their swaying motion and expansion by heat. A chimney near Marseilles, 115 feet high, was observed to oscillate one foot eight inches; when a sudden gust of wind struck the shaft it would vibrate four or five times before coming to rest. Excessive oscillations are frequently prevented by loading the cap.

CHIMNEY DESIGN.

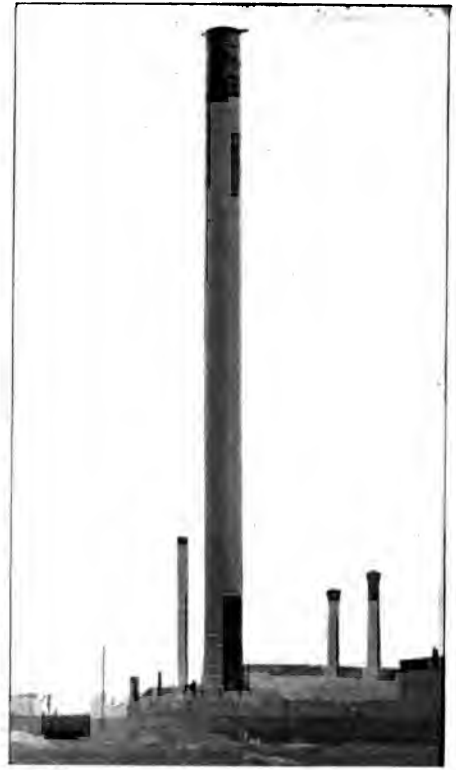
M. Bassine—*Engineering News*, April 22, 1897, p. 247—considers a chimney as a vertical beam fixed at the base, and thus determines the limiting conditions of pressure and tension in the different horizontal sections. He recommends an exterior profile with a batter ranging from 33.1 on 1 to 25 on 1, and divides the vertical height into sections of from 16 to 20 feet each, with the thickness of wall constant for each section, and decreasing by 1½ to 2½ inches in each ascending section. He

* For chimneys built of common red brick.



ILLUS. No. 13.
THE NASSAU ELECTRIC RAILWAY CO., BROOKLYN, N. Y.
Self-Supporting Stack, 12 feet diameter, 165 feet high.

ILLUS. No. 14.
PHILADELPHIA SMELTING AND REFINING CO., PUEBLO, COL.
Self-Supporting Stack, 13 feet 8 inches in diameter, by 130 feet high.



ILLUS. No. 15.
MIDVALE STEEL CO., PHILADELPHIA, PA.
Self-Supporting Stack, 11 feet 6 inches in diameter by 200 feet high.

prefers an octagonal base with a height equal to one-fifth of the height of the chimney. The foundation should be a truncated pyramid with a square base, and sides inclined at an angle of at least 45 degrees. The length of the sides of the foundation should vary between $\frac{1}{7}$ and $\frac{1}{8}$ of the height of the chimney.

Stability.—Rankine says: "It had been previously ascertained, by observation of the success and failure of actual chimneys, and especially those which respectively stood and fell during the violent storms of 1856, that in order that a round chimney may be sufficiently stable, its weight should be such that a pressure of wind, of about 55 pounds per square foot of a plane surface, directly facing the wind, or $27\frac{1}{2}$ pounds per square foot of the plane projection of a cylindrical surface, . . . shall not cause the resultant pressure at any bed-joint to deviate from the axis of the chimney by more than one-quarter of the outside diameter at that joint."

The angle of repose for dry masonry and brickwork is 31 to 35 degrees, and the coefficient of friction, 0.6 to 0.7; the coefficient of friction for masonry on dry clay is 0.51; the coefficient of friction for masonry on wet clay is 0.33.

Rankine says: "Towers and chimneys are exposed to the lateral pressure of the wind, which may be assumed to be horizontal, and of uniform intensity at all levels." The inclination of the surface of a tower or a chimney to the vertical is seldom sufficient to be worth taking into account, in determining the pressure of the wind against it.

The greatest intensity of the pressure of the wind against a flat surface directly opposed to it, hitherto observed in Great Britain, has been 55 pounds per square foot. Note, see p. 31, St. Louis, Mo., chimney in tornado; and this result, obtained by observations with anemometers, has been verified by the effects of certain violent storms in destroying chimneys and other structures.

In any other climate, before designing a structure intended to resist the lateral pressure of the wind, the greatest intensity of that pressure should be ascertained either by direct experiment, or by observations of effects of the wind on previous structures.

The total pressure of the wind against the side of a cylinder is about one-half the total pressure against a diametral plane of that cylinder.

Let Fig. 1 represent a chimney of any section, and let it be required to determine the conditions of stability of a given

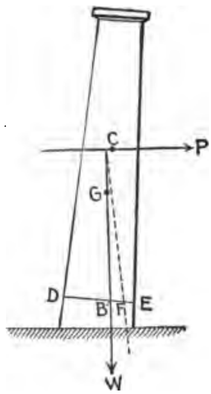


FIG. 1.

bed-joint DE. Let A denote the area of a diametral vertical section of the part of the chimney above the given joint, and p the greatest intensity of pressure of the wind against a flat surface.

Then the total pressure of wind against the chimney will be sensibly:

$$P = pA \text{ for a square chimney;}$$

$$P = p\frac{A}{2} \text{ for a round chimney;*}$$

$$P = \tfrac{3}{4}pA \text{ for a hexagonal chimney;}$$

$$P = 0.7\,pA \text{ for an octagonal chimney;}$$

and its resultant mav, without appreciable error, be assumed to act in a horizontal line through the centre of gravity of the

* In Germany $P = p\frac{2A}{3}$ is used for round chimneys. The most dangerous wind direction for polygon cross-sections is "across corners," because the edge tension becomes the greatest for this direction.

ILLUS. No. 16.

DOBSON & BARLOW CHIMNEY, BOLTON, ENGLAND.

$367\frac{1}{2}$ feet high.

vertical diametral section C. Let H denote the height of that centre above the joint DE; then the moment of the pressure is

$$H \times P = HpA \text{ for a square chimney;}$$
$$H \times P = Hp\frac{A}{2} \text{ for a round chimney;}$$
$$H \times P = Hp\tfrac{3}{4}A \text{ for a hexagonal chimney;}$$
$$H \times P = Hp \times 0.7A \text{ for an octagonal chimney;}$$

and to this the least moment of stability of the portion of the chimney above the joint DE should be equal.

For a chimney whose axis is vertical, the moment of stability is the same in all directions.

But few chimneys have their axes exactly vertical, and the least moment of stability is obviously that which opposes a lateral pressure acting in that direction in which the chimney leans.

Let G be the centre of gravity of the part of the chimney which is above the joint DE and B, a point in the joint DE vertically below it; and let the line $\overline{DE} = t$ represent the diameter of that joint which traverses the joint B. Let q' represent the ratio which the deviation of B from the middle of the diameter DE bears to the length t of that diameter.

Then the least moment of stability is denoted by

$$(49) \quad W \times \overline{BF} = (q - q')\ Wt.$$

The value of the co-efficient q is determined by considering the manner in which chimneys are observed to give way to the pressure of the wind.

This is generally observed to commence by the opening of one of the bed-joints, such as DE at the windward side of the chimney.

A crack thus begins which extends itself in a zig-zag form diagonally downward along both sides of the chimney, tending to separate it into two parts, an upper leeward part and a lower windward part, divided by a fissure from each other.

The final destruction of the chimney takes place, either by the horizontal shifting of the upper division until it loses its support from below, or by the crushing of a portion of the brickwork at the leeward side, from the too great concentration

of pressure upon it, or by both causes combined; and in either case the upper portion of the structure falls in a shower of fragments, partly into the interior of the portion left standing, and partly on the ground beside its base.

It is obvious that, in order that the stability of a chimney may be secure, no bed-joint ought to tend to open at its windward edge; that is to say, there ought to be some pressure at every point of each bed-joint, except the extreme windward edge, where the intensity may diminish to nothing; and this condition is fulfilled with sufficient accuracy for practical purposes, by assuming the pressure to be an uniformly varying pressure, and so limiting the position of the centre of pressure F, that the intensity of the leeward edge, E, shall be double the mean intensity.

Chimneys in general consist of a hollow shell of brickwork, whose thickness is small compared with its diameter; and in that case it is sufficiently accurate for practical purposes to give q the following values:

For square chimneys, $q = \frac{1}{3}$;
For round chimneys, $q = \frac{1}{4}$;

$$\text{For other shapes, } q = \frac{\text{Moment of Inertia.}}{2Fe^2}$$

F = area of section.
e = distance of outer fibre from neutral axis.

The following general equation, between the moment of stability and the moment of external pressure, expresses the condition of stability of a chimney:

$$(50) \qquad HP = (q - q')\ Wt.$$

This becomes, when applied to square chimneys;

$$(51) \qquad HpA = (\tfrac{1}{3} - q')\ Wt;$$

and when applied to round chimneys;

$$(52) \qquad \frac{HpA}{2} = (\tfrac{1}{4} - q')\ Wt.$$

The following approximate formulæ, deduced from these equations, are useful in practice:

Let B be the mean thickness of brickwork above the joint

ILLUS. No. 17.

A Brick Chimney Staging. Chimney—Plume & Atwood Manufacturing Company, Thomaston, Conn.

150 feet high, 9 feet outside diameter at top.

DE under consideration, and b the thickness to which that brickwork would be reduced if it were spread out flat upon an area equal to the external area of the chimney. That reduced thickness is given with sufficient accuracy by the formula:

$$(53)\quad b = B\left(1 - \frac{B}{t}\right),$$

but in most cases the difference between b and B may be neglected.

Let w be the weight of a unit of volume of brickwork; being on an average 112 lbs. per cubic foot, or, if the brick are dense, and laid very closely, with thin layers of mortar in the joints, from 115 to 120 lbs. per cubic foot should be used. Then we have approximately

(54) for square chimneys, $W = 4wbA$;
(55) for round chimneys, $W = 3.14wbA$;

which values, being substituted in previous equations, give the following:

(56) for square chimneys, $Hp = (\frac{4}{3} - 4q')\, wbt$;
(57) for round chimneys, $Hp = (1.57 - 6.28q')\, wbt$.

These formulæ serve two purposes, first, when the greatest intensity of the pressure of the wind, p, and the external form and dimensions of a proposed chimney are given, to find the mean reduced thickness of brickwork, b, required above each bed-joint, in order to insure stability; and secondly, when the dimensions and form and the thickness of the brickwork of a chimney are given, to find the greatest intensity of pressure of wind which it will sustain with safety.

The shell of a chimney consists of a series of divisions, one above the other, the thickness being uniform in each division, but diminishing upward from division to division. The bed-joints between the divisions where the thickness of brickwork changes (including the bed-joint at the base of the chimney) have obviously less stability than the intermediate joints: hence it is only to the former set of joints that it is necessary to apply the formulæ.

Another generally accepted equation and statement in relation to the stability of a brick chimney-shaft is: that the total wind pressure against a chimney multiplied by one-half of the height of the chimney divided by the weight of the shaft above the section considered should be equal to or less than one-sixth of the outside diameter at the section considered. If $\frac{1}{6}$ then the maximum pressure at any point in the circumference will be double the average pressure.

Rankine's calculations upon the stability of the outer core of a 455½ feet chimney at Glasgow, Scotland,* are as follows:

TABLE No. 24

Divisions of chimney.	Height above ground.	External diameter.		Thicknesses.		Greatest pressure of wind consistent with security. Lbs. per square foot.
	Feet.	Feet.	Inches.	Feet.	Inches.	
V	435½	13	6	1	2	77
IV	350½	16	9	1	6	55*
III	210½	24	0	1	10½	57
II	114½	30	6	2	3	63
I	0 to 54½	35 0 to 40	0	2	7½	71

* Joint of least stability.

Fifty-five lbs. is but 4 lbs. above the highest noted wind pressure in the west of England.

The external diameter of the foundation of this chimney is 50 feet.

GENERAL NOTES.

Material.—All material entering into the construction of a chimney, its connections, and foundations should be of the best obtainable of their respective kinds. This applies even more forcibly to steel chimneys.

Progress.—Foundations for brick chimneys should be laid up a month before the superstructure is built to allow the mortar to set thoroughly and harden; after this the shaft should be erected at from three to five feet of height per day, and the walls should be trued up or plumbed every three feet in height with the greatest care.

Weather.—Brick chimneys should be commenced and fin-

* The foundation of this chimney has a depth of 20 feet and a diameter of 50 feet.

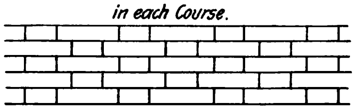
ILLUS. No. 18.
Pumping Station, Water Works, Manchester, N. H.

ished in the spring or summer months; take advantage of fine days, and do not lay brick at frosty or freezing temperatures.

Bonding.—In England some chimneys are laid up in Flemish Bond; some in half brick bond, twice as many stretches as in Old English Bond. In the United States a great many chimneys are laid up in a bond made of one course of headers to five or six courses of stretchers, as shown.

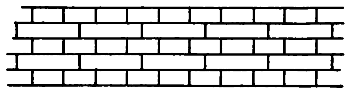
Often in large brick chimneys, an iron band or hoop, such as $\frac{1}{4}$ by 2 inch or 3 by 3 inch T-iron is laid within the brick wall at intervals of three to five feet, having a continuous circumference, which is very good practice when the walls are over eight inches thick.

Alternate Stretchers and Headers in each Course.



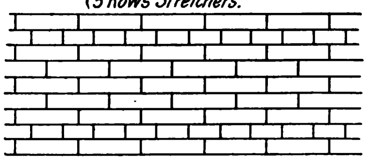
Flemish Bond

Alternate Courses of Stretchers and Headers.



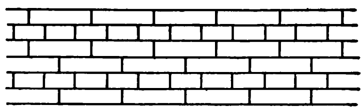
Old English Bond.

{ 1 Row Headers, 5 Rows Stretchers.



Usual Bond.

2 Rows Stretchers.



Old English Bond.

Mortar.—It is customary in brick chimneys to use a lime mortar for the inner shell until within a few feet of the top, where cement mortar is used because of its strength of adherence; the outer shell being laid up in mortar of lime, cement, and sand.

The practice of some engineers is to build a ring of chimney about eight feet high laid up in cement mortar, alternating with a similar ring laid up in lime mortar, thereby gaining greater strength and tenacity.

Chimneys which are used to convey the gaseous products of chemical reactions are laid their whole height in cement mortar; the interior surface of the flue laid up as true and smooth as it is possible to make it, and all joints entirely filled.

English refuse-destructor chimney constructed for the Hornsley Local Board (England) for use in connection with its sanitary depot for treatment of house refuse.—*American Gas Light Journal.*

Principal Dimensions.

	Feet.	Inches.
Total height, bottom of foundation to top of capping	244	0
Height from ground line to top capping	217	0
Outside diameter at ground surface	18	3
Inside diameter at ground surface	12	3
Outside diameter at top, under capping	8	6
Inside diameter at top, under capping	6	3

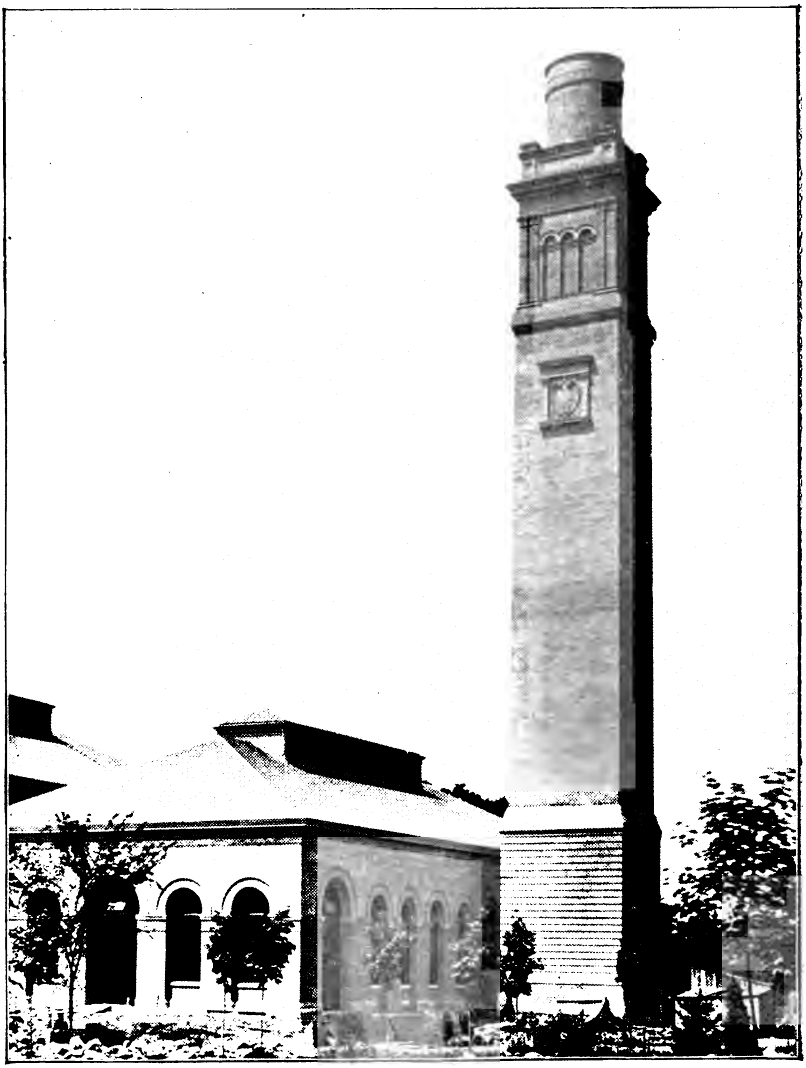
The bricks used in its construction were good London stocks, 9 by $4\frac{1}{2}$ by $2\frac{3}{4}$ inches, and the work throughout is laid in English bond, with Dorking lime mortar in the proportion of three Thames sand to one of lime. No grouting was used in any part of the construction. The foundation bed is clay, 27 feet below ground line. On this a block of concrete was formed, 39 feet square, and $16\frac{1}{2}$ feet deep, composed of six parts Thames ballast to one of Portland cement.

The brick footings in the cement are 33 feet square at base, and built up to ground line, which is 10 feet 6 inches from top of concrete bed, with regular offsets of $2\frac{1}{4}$ by $6\frac{3}{4}$ inches.

The shaft proper, starting from top of footings, is built up in six sections, commencing at the base:

	Feet.	Inches.		Bricks.
First section	30	0	by	4
Second section	34	6	by	$3\frac{1}{2}$
Third section	34	6	by	3
Fourth section	37	0	by	$2\frac{1}{2}$
Fifth section	37	0	by	2
Sixth section	21	0	by	$1\frac{1}{2}$
Seventh (cap)	23	0	by	2
	217	0		

The cap portion, which is constructed in white-glazed and blue Staffordshire bricks, is ornamented with a circular cast-iron capping weighing 2,200 lbs., cast in six segments, and bolted together by internal flanges, and forms a very good finish to this tall shaft.



ILLUS. No. 19.
QUEEN LANE PUMPING STATION, PHILADELPHIA, PA.

A fire-brick lining, or inner shaft, is built up to a height of 60 feet, the lower 30 feet in 9-inch, and the upper in $4\frac{1}{2}$-inch work set in fire-clay.

An annular space of 15 inches is left at the base, between the fire-brick lining and the main shaft, to admit of expansion in the fire-brick.

The top of lining nearly touches the main shaft, which is corbelled over to fire-brick lining to prevent any deposit accumulating in the annular space.

Cast-iron inlets 9 by 6 inches are provided at ground level to admit cold air, and to prevent the inrush striking the fire-brick lining; a $4\frac{1}{2}$-inch brick pier, 2 feet high, is built between the two shafts.

Two rings at the base and one toward the top, of hoop-iron bonding, $\frac{3}{16}$ by $1\frac{1}{2}$-inch, are built in main shaft, about every 3 feet 6 inches in height.

The connection between flues of boilers and furnaces with main shaft is made by an arched flue opening, 9 feet by 3 feet 3 inches at the base, and a soot door is also provided, whereby access can be obtained to the inside of shaft when required.

The time occupied in building this shaft was a little over five months, commencing in July and finishing in December, 1888.

The bricklaying was continued all through the foggy weather in the latter month, although the workmen could not see the ground through the fog below.

A lightning conductor is fixed to the shaft, composed of two copper tapes or bands, $1\frac{1}{4}$ by $\frac{1}{8}$ inch, winding spirally around the outer circumference to underside of cap, where they are connected to a ring encircling the shaft, and from thence to 6 copper rods, 1-inch diameter, which are carried to a height of 4 feet above the cap, and the rods terminate with crow-feet ends. The tapes are joined at a distance of about 40 feet from the base, north of the shaft, and 18 feet below the ground level, and terminate in a copper earth-plate 3 feet by 2 feet by $\frac{1}{2}$ inch.

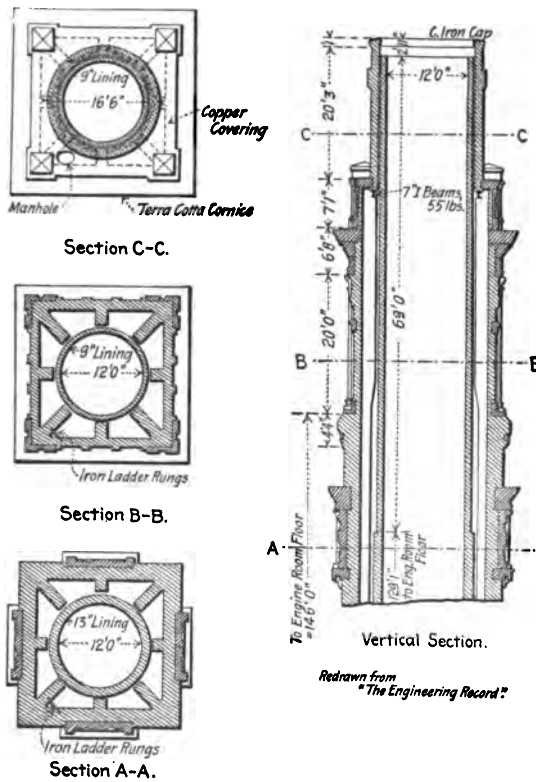
Outside scaffolding was used, and no accident whatever occurred during the construction. The shaft forms a conspicuous landmark to the surrounding locality, and dwarfs all other similar structures for miles around.

Queen Lane Pumping Station, Philadelphia, Pa., completed in 1896, is a brick chimney with a very elaborate exterior casing, as may be seen from the engraving shown.

The flue is 12 feet in diameter, perfectly straight.

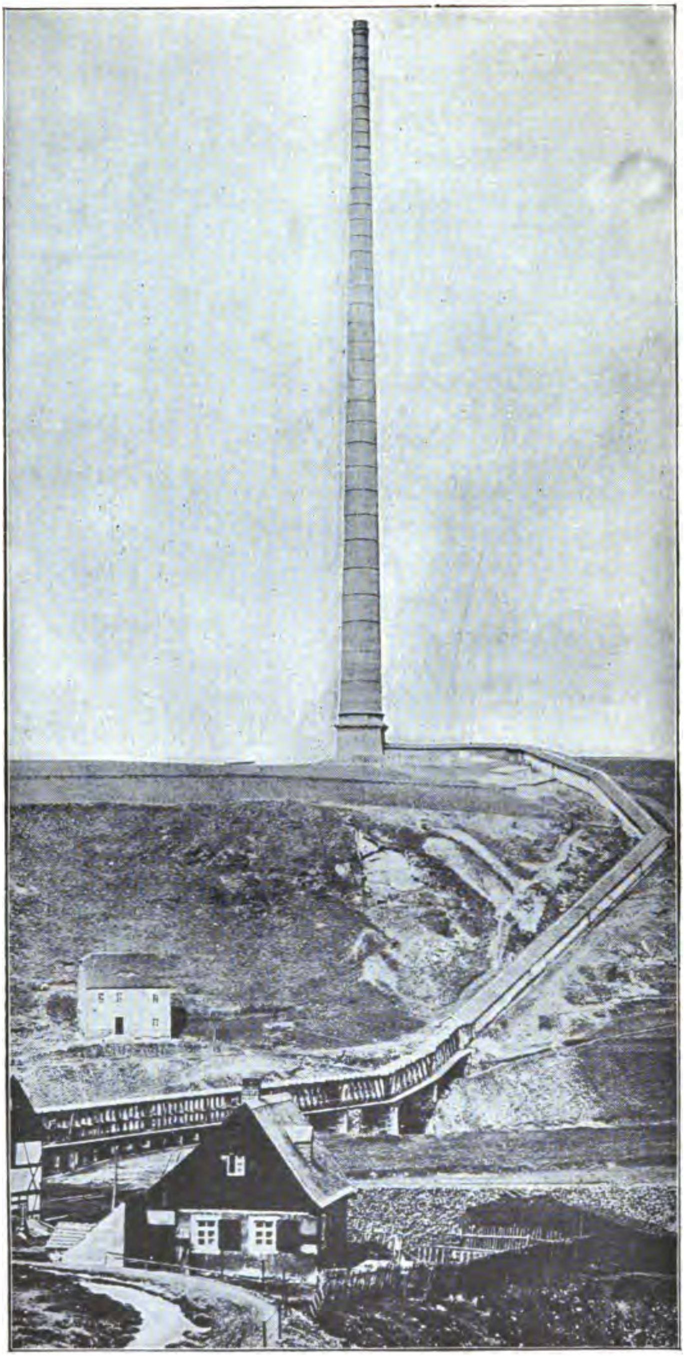
Height, 200 feet above ground.

The foundation is 24 feet below grade level, and its bottom course 37 feet square; the base of chimney above grade is 24 feet square.



ILLUS. No. 20.

QUEEN LANE PUMPING STATION, CHIMNEY SECTIONS.



ILLUS. No. 21.
ROYAL SAXONY SMELTING WORKS, OF HALSBRÜCKE, NEAR FREIBURG, IN SAXONY.
Height, 460 feet; internal top diameter, 8 feet 4 inches.
Built by H. R. Heinicke.

BRICK CHIMNEY AT IMPERIAL FOUNDRY NEAR FREIBURG, IN SAXONY.

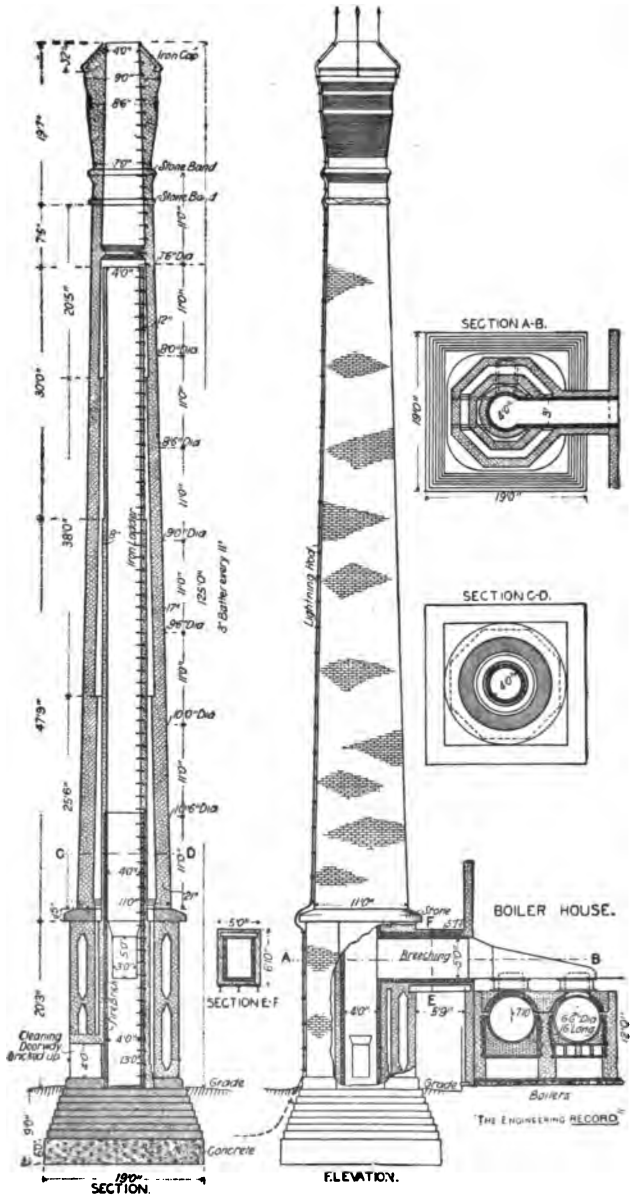
Flue 453 feet high, with an interior or flue-diameter of 15 feet 9 inches. Projected and designed by Engineer Huppner, it is built on the right bank of the river Mulde, on a hill which rises 259 feet above the ground on which the furnaces stand, so that the top of the chimney will be 712 feet above the works.

The base is 39 feet 4½ inches square, and 28 feet 6 inches high, and at its top the chimney proper begins.

The works being on the left or opposite bank of the river, the flues running from the furnaces are carried across on a bridge built for the purpose, and then up the hill to the point where they enter the chimney.

The total length of these flues or ducts is 3,228 feet.

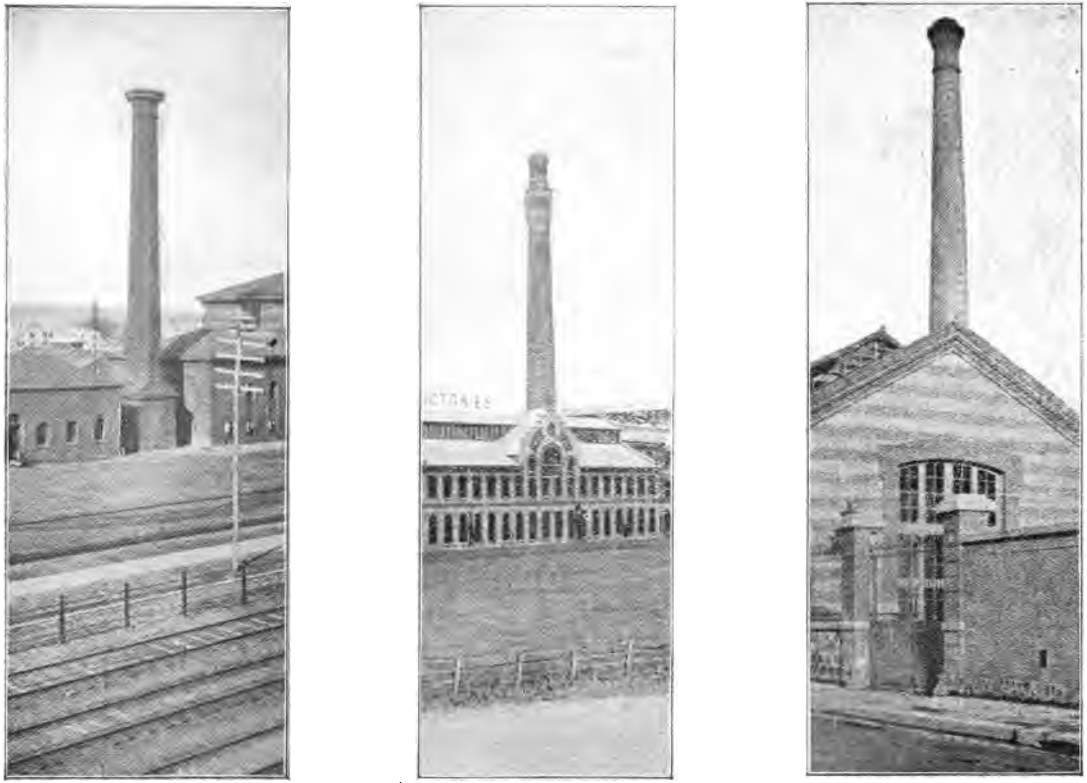
The chimney is built of brick entirely, and cost $40,000.—*Railroad and Engineering Journal.*



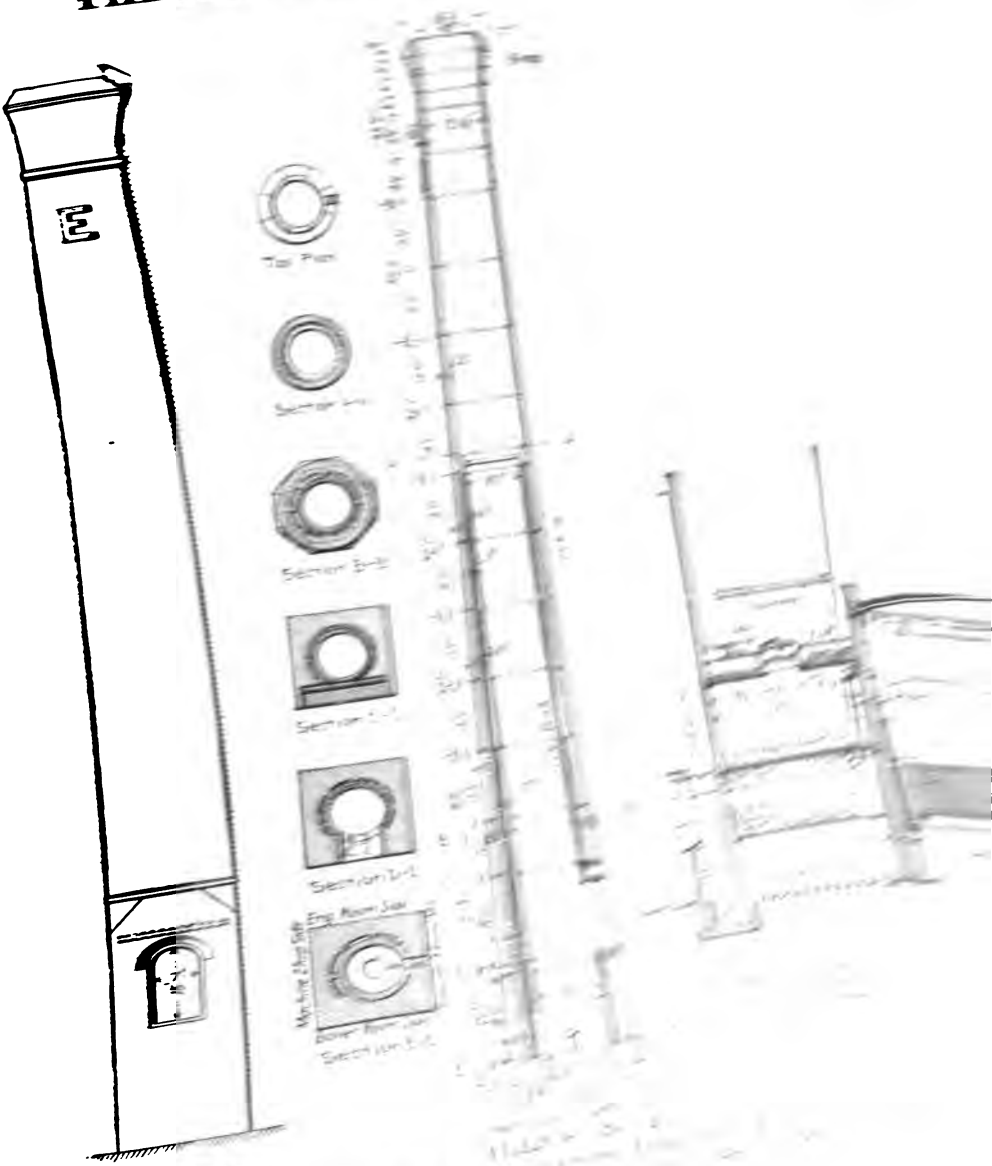
ILLUS. No 22.

Brick Chimney, Tweedvale Manufacturing Company.

4 feet diameter by 125 feet high.—*Eng. Record,* vol. xxxii., p. 407.



ILLUS. No. 23.
THREE BRICK CHIMNEYS.



EDISON ELECTRIC [illegible]
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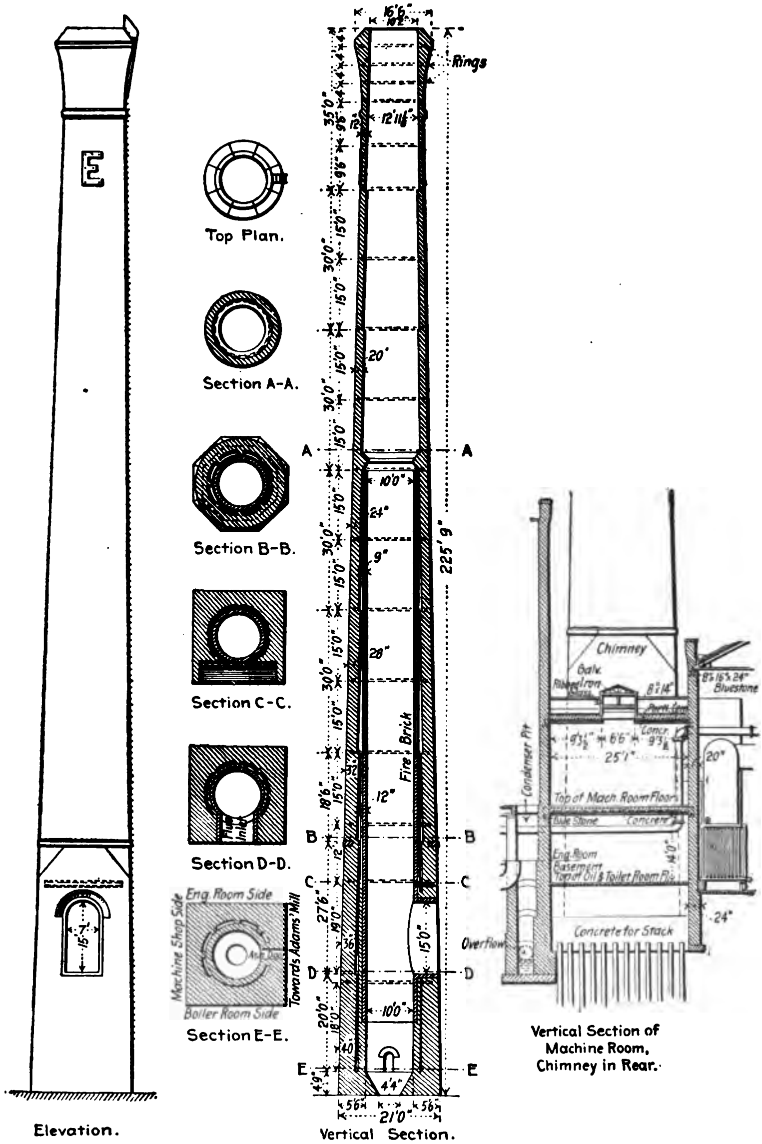


ILLUS. No. 24.

EDISON ELECTRIC ILLUMINATING COMPANY, PATERSON, N. J.

From *Electrical Engineer*, vol. xxii., Dec. 9, 1896.

EDISON ELECTRIC ILLUMINATING CO., PATERSON, N. J., 1896.

Flue, 10 feet diameter, 225 feet high; calculated for 4,000 boiler horse-power.

The smokestack is the highest but one in the State of New Jersey, and its construction deserves special attention. The height from the foundation to the top is 235 feet, with a 10-foot flue, and its diameter at the base is 22 feet; the other dimensions will be found in the detail drawing, Fig. 9. The foundation on which it is built is piling driven into the earth and over this is laid 5 feet of concrete. The chimney is double walled for 130 feet 9 inches, and at every 15 feet a wrought iron ring is set into the brickwork, in this way bonding the chimney together. There were 900,000 bricks used in the construction of this chimney, and an electric hoist was used during its construction, no outside staging whatever being employed. The material was hoisted on the interior of the chimney.

In their old plant the company used an octagonal brick chimney; flue, 8 feet diameter by 200 feet high; calculated for 2,500 boiler horse-power, and it is reported to have furnished draught for 5,000 lbs. of coal per hour.

ILLUS. No. 25.

EDISON ELECTRIC ILLUMINATING COMPANY, PATERSON, N. J.

Amoskeag Manufacturing Company, Manchester, N. H. Architect, George W. Stevens; Steam Engineer, Charles H. Manning; builders, Amoskeag Manufacturing Company.

Description.—Circular brick; built 1883; 60 days occupied in construction.

Dimensions.

	Feet.	Inches.
Total height, including foundations	265	0
Height from ground line to top	255	0
Outside measurement at foundation	25	8
Inside measurement at foundation.................	19	8
Outside diameter at ground surface	25	0
Inside diameter at ground surface.................	19	8
Thickness of brick at ground surface...............	2	8
Outside diameter at top (exclusive of cornice)......	12	6
Inside diameter at top............................	10	0
Thickness of brickwork at top.....................	1	3

Foundation.—The shaft is founded on a bed of ledge. No concrete used.

Pressure.—On foundations (as given by the firm) is 10,220 lbs. per square foot.

Bond.—Headers every tenth course.

Batter.—1 in 40.8.

Bricks.—1,000,000 common bricks used in construction.

Weight.—2,330 tons.

Scaffold.—Outside scaffold used, costing $750.

Duty.—This shaft was designed to burn 18,000 lbs. of anthracite coal per hour. It carries off the fumes from sixty-four boilers = 8,400 horse-power. The company chiefly manufacture ginghams, ticking, and fancy shirtings.

Inner Shaft.—The chimney has an inner shaft of 10 feet internal diameter.

Lightning Rods.—Wrought-iron; costing $95.

Cost.—Complete, $16,000.

Merrimack Manufacturing Company, Lowell, Mass. Engineer, J. T. Baker, C. E.; chimney built 1882.

Description.—Circular brick shaft, with inner shaft and core.

Dimensions.

	Feet.
Height above ground line	282
Outside diameter foundation	30
Outside diameter 2 feet 6 inches above ground	28
Inside diameter 2 feet 6 inches above ground	12
Inside diameter at top	12

Foundation.—The chimney is founded on a ledge of sandstone. The foundation, 30 feet in diameter, is built of granite blocks, laid on their natural beds. At the surface of the ground there is a dressed granite base 2 feet 6 inches in height, laid in clear Portland cement, the remainder of the foundation being in Rosendale cement and sand.

Upon this base is placed the brickwork, consisting of three cylinders, as follows:

Outer Shaft.—Batter, 0.42 inches per foot, for a height of 100 feet.

First section...	75½ feet high, 28 feet diameter	24	inches thick.
First section...	at junction of inner shaft....	36½	inches thick.
Second section	60 feet high	20	inches thick.
Third section..	70 feet high	16	inches thick.
Fourth section	74 feet high, including cap..	12	inches thick.
	279½ high above granite base.		

Inner Shaft.—Vertical, 18 feet diameter; 75½ feet high; 8 inches thick.

At this height the inner shaft connects with the exterior brickwork, making the masonry at that point 36½ inches thick, as above.

Lining or Core.—Uniform inside diameter, 12 feet.

It is entirely separate from the outside masonry, except the doorways and flue-openings, and is built up as follows:

First section....	100	feet high, 16 inches thick.
Second section..	60	feet high, 12 inches thick.
Third section....	90	feet high, 8 inches thick.
Fourth section..	29½	feet high, 4 inches thick.
	279½	feet high above granite base.

Construction.—The core was laid in mortar of lime and sand; the outside shell in lime, cement, and sand.

Ladder and Lightning Conductor. — On one side of the chimney is a ladder of iron extending from the ground to the top, and on the opposite side is a $\frac{3}{4}$-inch galvanized iron-wire rope, both ladder and rope being connected with a copper ring, having four spurs, the central point of which extends 8 feet above the top of the shaft. The bottoms of both ladder and rope are connected to a 16-inch water-pipe.

Duty.—Two wrought-iron flues enter the chimney, one 5 feet by 6 feet, and the other 5 feet by 11 feet. The chimney is constructed to provide for 15 sets of boilers; only 12 are now in use. Each set has 103$\frac{1}{4}$ square feet of grate surface, and is rated at 300 horse-power.

Weight.—Chimney, 3,392 tons; cap, 18,600 lbs.

Materials.—Brick used, 1,101,000; 6,875 cubic feet stone masonry.

Cost.—$18,500.

Holyoke Machine Company (1883). Flue, 42 inches square by 120 feet high.

Double Wall.—Inner wall to within 24$\frac{1}{2}$ feet of top, above this wall the flue is enlarged to 48 inches square.

There are three arches in each side with stone water-tables above each, and a double arch at the top of chimney.

The top is covered with a casting bolted together in sections; 144,044 bricks were used in its construction, and its cost was, aside from cast cap, $2,160.60.

Weight of cast cap was 869$\frac{1}{2}$ lbs., which, with labor, adds $31.41 to cost, or a total of $2,192.01.

An internal ladder of round iron provides means of access to the top.

Each wall is built in three steps or thicknesses, not given above the base, where the outer wall is 16 inches, 54 feet high, those above it probably 12 inches, 23 feet high, and 8 inches for the balance, 12-inch inner, 39 feet core; those above probably 8 inches, 45 feet, and 4 inches, 55$\frac{1}{2}$ feet high.

A very clear engraving of this chimney can be found in the *American Machinist*, March 24, 1883.

Pacific Mills, Lawrence, Mass. Architect and builder, H. F. Mills, C. E.; built 1873.

Description.—Brick, octagonal outer shaft, circular inner shaft, vertical inner lining. Shaft situate 210 feet from boilers.

Dimensions.

	Feet.	Inches.
Total height	242	0
Height of outer shaft, including footings	233	0
Height of inner lining	234	0
Outside measurement, outer shaft at base	20	0
Outside measurement, outer shaft at top, under projecting cornice	11	6
Inside diameter, vertical flue	8	6

Foundation.—Foundation bed, 19 feet below ground; coarse gravel; concrete, 35 feet square, enclosed by pine-sheet piling 1 foot thick; rubble masonry of granite, in Rosendale cement, 7 feet high.

Outer Shaft.—This is constructed in six sections, viz.:

First section	12 feet high, 28 inches thick.
Second section	18 feet high, 24 inches thick.
Third section	20 feet high, 20 inches thick.
Fourth section	40 feet high, 16 inches thick.
Fifth section	60 feet high, 12 inches thick.
Sixth section	83 feet high, 8 inches thick.
	233 feet high above granite masonry.

Inner Shaft:

First section	27 feet high, 24 inches thick.
Second section	154 feet high, 12 inches thick.
	181 feet.

Lining:

First section	20 feet high, 20 inches thick.
Second section	17 feet high, 16 inches thick.
Third section	52 feet high, 12 inches thick.
Fourth section	145 feet high, 8 inches thick.
	234 feet above granite masonry.

Construction.—The foundations were laid in mortar of Rosendale cement and sand; the outer shell in mortar of Rosendale cement, lime, and sand; and the flue-walls in mortar of lime and sand.

Duty.—In the winter of 1873, the vertical flue having reached 90 feet in height above ground, boilers having 542 square feet of grate surface were connected with the chimney, with satisfactory results. The chimney was designed to serve boilers having 700 square feet of grate surface.

Weight.—The approximate weight of the chimney is 2,250 long tons.

Bricks.—There were 550,000 bricks used in the construction of the shaft.

Lightning Conductor.—The shaft was struck by lightning in June in 1880, after which date a lightning-rod was put up. It consists of a seamless copper tube, $\frac{5}{16}$ inch thick, 1 inch inside diameter, at the top of which are seven points radiating from a ball 4 inches in diameter, the top of the central point being $8\frac{1}{2}$ inches above the iron cap. The rod is attached to the chimney by brass castings, and is connected at the base to a 4-inch iron pipe extending 60 feet to a canal.

This is a very weak chimney, the diameter at the base is 15 feet; one-tenth of the height (a common rule) would give 21.1 feet.

J. B. Francis, in a report on the above chimney, says 44 lbs. wind-pressure per square foot would blow the chimney down.

Brick chimney of the Narragansett Electric Lighting Company, at Providence, R. I. Designed by Messrs. Remington and Henthorn, Providence, R. I.

The foundation of the chimney consists of piling and concrete, and to arrange for it 44 square feet was excavated 5 feet 6 inches below the zero line of high water, and the sides protected by 3-inch spruce sheet-piling 16 feet long.

Over this excavation the pile-driver, having a ram weighing 2,200 pounds, was rolled.

Spruce piles, 50 feet long, were driven as far as possible without breaking, and were spaced 30 inches centre to centre, as shown in Fig. 1.

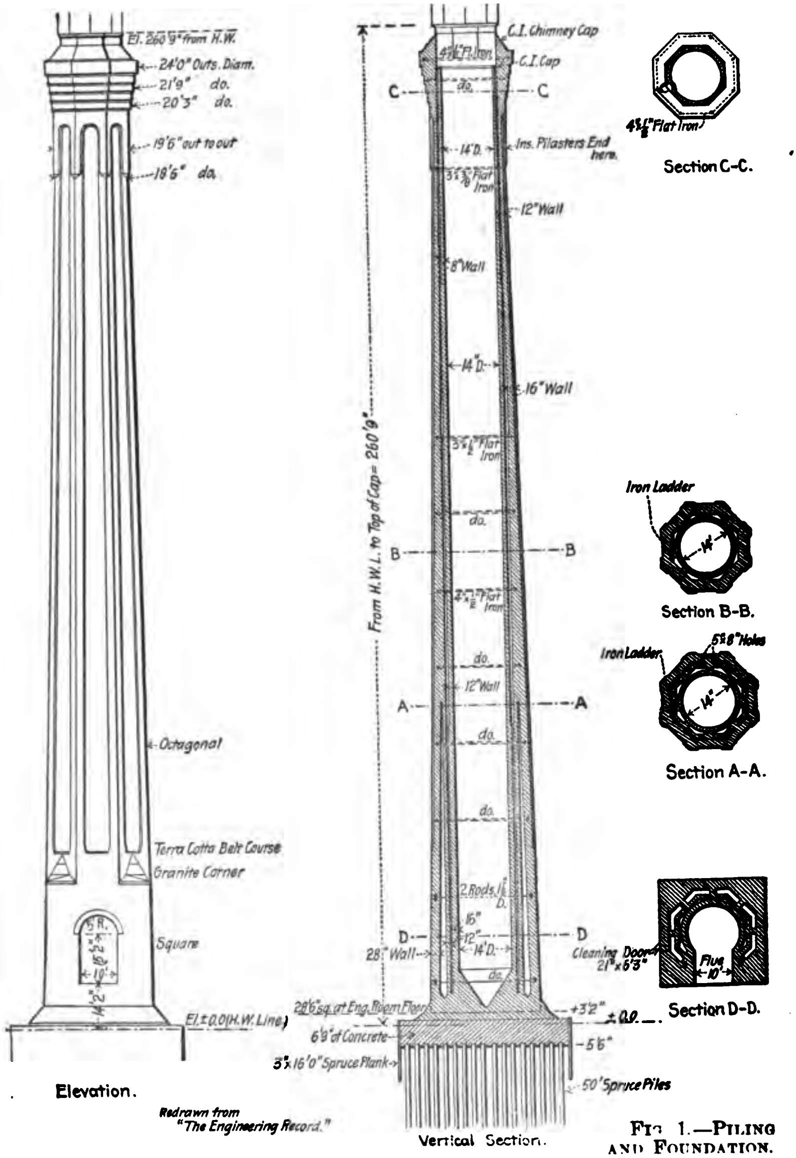


FIG. 1.—PILING AND FOUNDATION.

ILLUS. No. 26.

BRICK CHIMNEY, NARRAGANSETT ELECTRIC LIGHTING COMPANY, PROVIDENCE, R. I.
260 feet 9 inches high. Flue, 14 feet diameter.

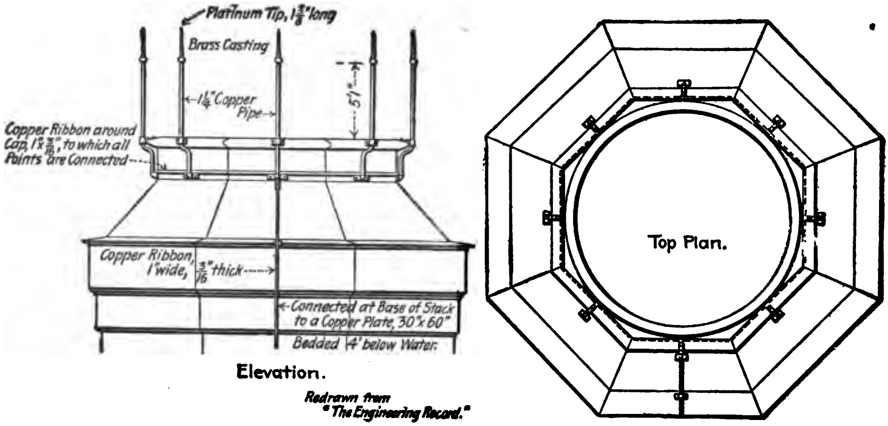


FIG. 2.—CHIMNEY CAP—LIGHTNING PROTECTION.

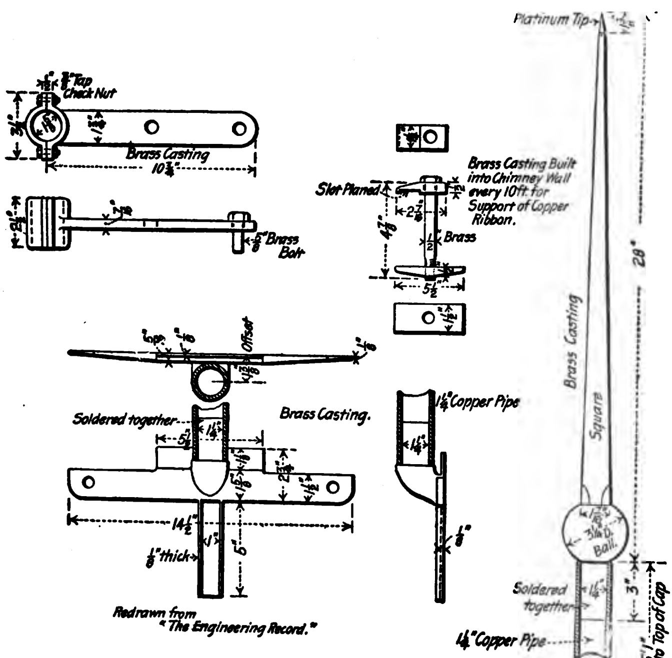


FIG. 3.—LIGHTNING FIXTURES.

ILLUS. No. 27.

NARRAGANSETT ELECTRIC LIGHTING COMPANY, PROVIDENCE, R. I.

There are, however, many more piles shown in this cut, but those were driven to sustain other structures alongside. In the drawing of chimney, of which there are 231 piles, they are shaded lightly that they may be more readily recognized.

These piles are cut off uniformly at 5 feet below the high-water line, the earth around their heads thus being 6 inches below their tops. The intervening space between the sheet-piling was filled in with concrete composed of one part of Norton's hydraulic cement, two parts sand, and three parts coarse gravel and broken stone.

This mass was carried up to the 1 foot 3-inch level, and consequently, formed a foundation 6 feet 9 inches thick, with the head of each pile projecting 6 inches therein. This was then covered with earth and allowed to season during the winter. On May 31, 1889, work was resumed by laying the first brick of the chimney. This was carried up in the form of a square of 36 feet, to a height of 3 feet 2 inches, and from that level the base of the chimney proper, which was 28 feet 6 inches square, was started.

The centre of the chimney was fixed by building into the chimney a cast-iron plate, upon which was a well-defined centre mark.

From this centre mark all measurements and plumbing were established while the chimney was being built.

As each 20 feet in height was built, the centre of its axis was re-established, and if any deviation from ~~the~~ plumb was found it was corrected before the next 20-feet level was reached.

The base of the chimney, as before stated, is 23 feet 6 inches square; consists of three walls, an outer wall 28 inches thick, an intermediate wall, octagonal in form, 12 inches thick, and a core wall, circular in section, 16 inches thick. The outer and intermediate walls are joined together by pilasters 12 inches thick.

In commencing the base of the core wall each course of brick was set back 2½ inches from the previous course, until the inside diameter, 14 feet, was reached, when the wall was carried plumb 16 inches in thickness up to the 78 feet 2-inch level, where it was reduced to 12 inches, and run up to 193 feet 2 inches, where it was again reduced in thickness to 8 inches,

and thus carried to 249 feet 9 inches. This wall, complete, was laid up in lime mortar which had been slaked from three to six months before using.

The outer wall, of rectangular cross-section, was carried up to the 38 feet 2-inch level, where, at each of the four corners, cut granite blocks were laid to change from a square to an octagonal cross section.

The chimney was built entirely from the inside platforms, the masons working overhanded, and thus no staging was necessary on the outside. Up to the level of the granite work all the stock used was carried up a ladder placed on the outside. But at this point there was constructed inside the 14-foot chimney-flue an elevator, fitted with safety clutches, and capable of carrying a thousand pounds, although not more than four hundred and fifty was allowed to be placed upon it at any one time; and thereafter everything used in the process of construction was sent up the elevator, to hoist which a 19-strand steel cable was used. The temporary framework inside the flue consisted of four 6 by 8-inch timbers, laid across each other at right angles in pairs, and built into the walls at intervals of every 5 feet.

Through the opening at the centre the elevator passed.

Over these timbers was laid a platform of 2-inch plank, upon which the masons performed their work. To these 6 by 8-inch horizontal timbers, at opposite corners, were bolted the vertical guides for the elevator and its upright framing, by which it was hoisted; these were spliced out at the top each alternate staging.

The opening for smoke-flues is 10 feet wide and 18 feet high, with a 28-inch arch of 5 feet radius. The lower part of the opening is on the 14 feet 2-inch level.

Directly below and above the opening on the 13 feet 2-inch and 33 feet 2-inch levels, were placed on each of the four sides of the chimney, and 8 inches from the outside surface of the wall, two 1¼-inch diameter rods, with 1½-inch ends, connected together by cast-iron plates 12 by 14 inches square.

Openings were left at each corner so that the nuts could be examined occasionally as the work dried out.

From and including the 53 feet 2-inch level, there were laid

edgewise at each 20 feet in height and 8 inches from the outside surface of the chimney wrought-iron bars of 4 inches by ½ inch with their ends bolted together, forming an octagon corresponding to that of the chimney. At the 153 feet 2-inch levels these braces were reduced in size to 3 inches by ½ inch, and were not again used until the 223 feet 2-inch level, or where the commencement of the head was reached, at which point bars 3 inches by ⅜ inch were bolted together in the wall. Their next application was in the head, where two braces made of 4-inch by ½-inch iron were used to help in binding the heavy brickwork together during construction, which had considerable overhang (2 feet 9 inches on each side).

With reference to the outside walls, the outer and intermediate walls, with their connected pilasters, were built as one structure and terminated on the 83 feet 2-inch level (see p. 106), where by the batter the outer wall is thus joined to the intermediate, and become one wall from that point.

At this level two holes 5 by 8 inches were left in each of the eight sides of the intermediate walls, so that the intervening space between the outer and inner walls might be ventilated, if by any possible chance gases should find access to this space.

These ventilating spaces or holes are in communication with the space between the outer wall and the core, which is carried nearly to the top.

An attempt has been made to protect the structure from lightning, by encircling the cast-iron cap with a copper ribbon 1 inch by $\frac{3}{16}$ inch thick, to which are connected, by riveted and soldered joints, eight brass upright sockets, one in the centre of each panel of the cap.

To these brass sockets castings are secured by soldered joints 1½-inch seamless drawn copper tubing, which extends upward above the top of the cap and conforms to the shape thereof, and after projecting 5 feet above the top of cap the tubes are each surmounted by a brass casting 28 inches long, tapering in cross section, and having at its extremity a platinum point 1⅜ inches long.

The encircling ribbon around the cap is connected to the ground ribbon by a brass casting thoroughly riveted and sol-

dered thereto, which, as it runs down the chimney is secured in position by brass clamps with bolts built into the brickwork as it progressed.

This arrangement, as a whole, is shown in detail in Figs. 2 and 3.

The lower end of the ribbon, which is 1 by $\frac{3}{16}$-inch copper, rolled in one piece 285 feet long, terminates in a copper plate 30 inches wide by 60 inches long, and $\frac{1}{16}$-inch thick, and is buried 4 feet below the natural level of the water in the soil of the premises.

This plate is buried in a load of powdered coke, 18 inches being placed above and 18 inches in thickness below the plate, and the whole filled up with gravel.

CHIMNEY AT CLARK'S THREAD WORKS, KEARNY, N. J.

"One of the tallest chimneys in America has been erected at the works of the Clark Thread Company, at Kearny, near Newark, N. J. The shaft is circular and 335 feet in height; it is 28 feet 6 inches in diameter at the base and 14 feet at the neck. Its internal diameter is 11 feet in one circular flue. The top is surmounted by a cast-iron coping weighing 6 tons and made in 32 sections bolted together by inside flanges.

"The foundation is concrete, made with 6 parts crushed limestone, 3 parts sand, and 1 part German Portland cement. This foundation is 40 feet square and 5 feet deep, resting on a bed of firm gravel. On this is founded the base of the chimney of brick and extending 4 feet above the surface of the ground. The material used was brick laid in mortar made 1½ sand to 1 of Portland cement. The shaft up to 160 feet in height was laid with mortar made of 6 parts sand, 2 parts lime, and 1 part cement; the sand and lime have stood for three months previously made up as mortar, and the cement was added just before use. The top of the chimney was laid in mortar made of 3 parts sand to 1 of lime and 1 of cement.

"The outer bricks were first quality North River, and the backing bricks were of a good quality New Jersey brick. At intervals of 20 feet an iron ring 4 inches wide, ¾ to ½ inch

thick placed edgewise, was built into the walls about 8 inches from the external surface.

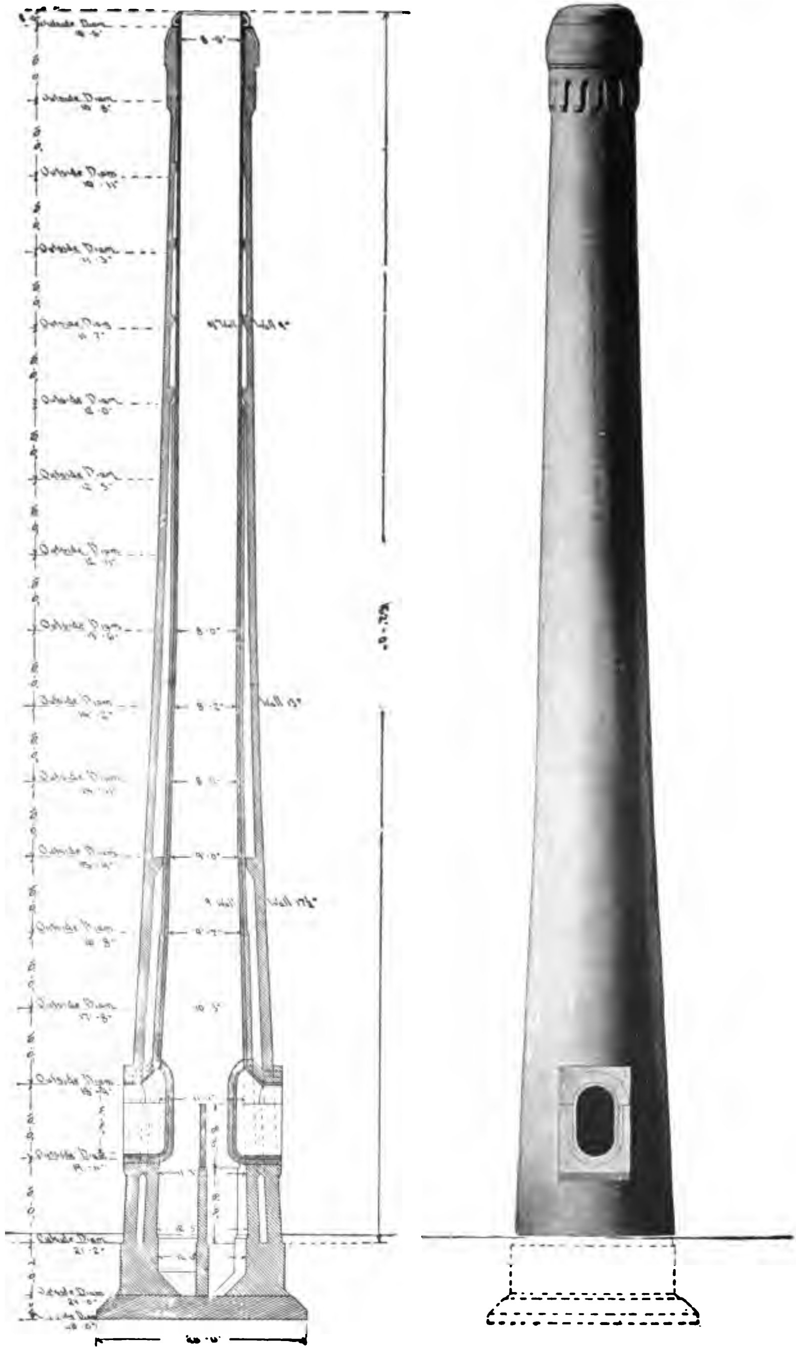
"At the base the chimney is double, with an outer wall 5 feet 2 inches thick, and inside of this is a second 20-inch wall placed about 20 inches inside the first. From the interior of the main wall eight buttresses are built up, nearly touching the main flue wall and intended to keep the flue proper from sagging. The interior wall starting with 20 inches in thickness is gradually reduced until at 90 feet high it is 8 inches thick, and at 165 feet it ceases entirely. No fire-brick was used in the lining.

"Two horizontal flues enter the base of the chimney directly opposite to each other, and a 12-inch deflecting wall is built across the shaft between these flues for a height of 16 feet. The two flues are arched and are 7 feet wide and 8 feet high, and in these flues will be placed feed-water heaters for the boilers; 21 boilers of 200 horse-power each will depend on this one chimney.

"The lifting was done by an inside elevator, with a 3½ by 3 foot platform, running between 4 by 6 inch guides braced against the inside walls. The interior platforms, erected at every few feet, rested upon two 3 by 8 inch beams built in the wall. The greater part of the brick laying was done by 8 bricklayers and 5 helpers, with 7 laborers on the ground supplying material.

"The foundation and base were put in and the shaft run up 18 feet in December, 1887. The work was again commenced in April, 1888, and finished in September, or in 150 days of 9 hours each. The total weight is about 5,000 tons, divided as follows: Brickwork, 9,051,900 pounds; concrete, 1,000,000 pounds; iron-work, 40,000 pounds. The base contains 1,600 square feet, which would give a load of about 2.8 tons per square foot. No permanent means of access to the top were provided; as if such access becomes necessary a small balloon can be sent up the shaft with a line and allowed to descend on the outside, and a line sufficiently heavy for use is thus carried up."—*Engineering News,* November 10, 1888.

With a flue temperature of 210° Fahr., a draft of 1¾ inches has been observed.



"Helios."

ILLUS. No. 28

BRICK CHIMNEY AT THE POWER HOUSE OF THE UNION DEPOT RAILWAY COMPANY, ST. LOUIS, MO.

BRICK CHIMNEY AT THE POWER HOUSE OF THE UNION DEPOT RAILWAY COMPANY, ST. LOUIS, MO.

This chimney was partially blown down by the tornado at St. Louis on May 27, 1896.

Construction.—It consisted of an outer shell built of selected hard-burned dark-red brick laid in a mortar of equal proportions of one part Portland cement to two parts sand, and one part lime to two parts sand.

Bricks laid with push-joints under inspection, and all joints are well filled.

The inner core is built of a ring of 4½-inch fire-clay brick, re-inforced in the lower section by a ring of hard-burned red brick.

The fire-brick are laid in fire-clay. Each shell is finished at the top by a cast-iron cap 2 feet deep, of ½-inch metal, secured to the brickwork by bolts. The inner shell is separated from the outer one by a varying distance; the dimensions, as planned, give this distance as a minimum of 2 inches at the top, and the same at 50 feet below the top where the section changes.

The inner shell is stayed by brackets built into the outer shell at intervals of 10 feet vertically. There are six of these brackets on a level, each having a face of about 8 by 8 inches. (See American Society of Civil Engineers. Proceedings, January, 1897. Baier on Tornadoes.)

BRICK CHIMNEY AT THE OMAHA AND GRANT SMELTING AND REFINING WORKS, DENVER, COL.

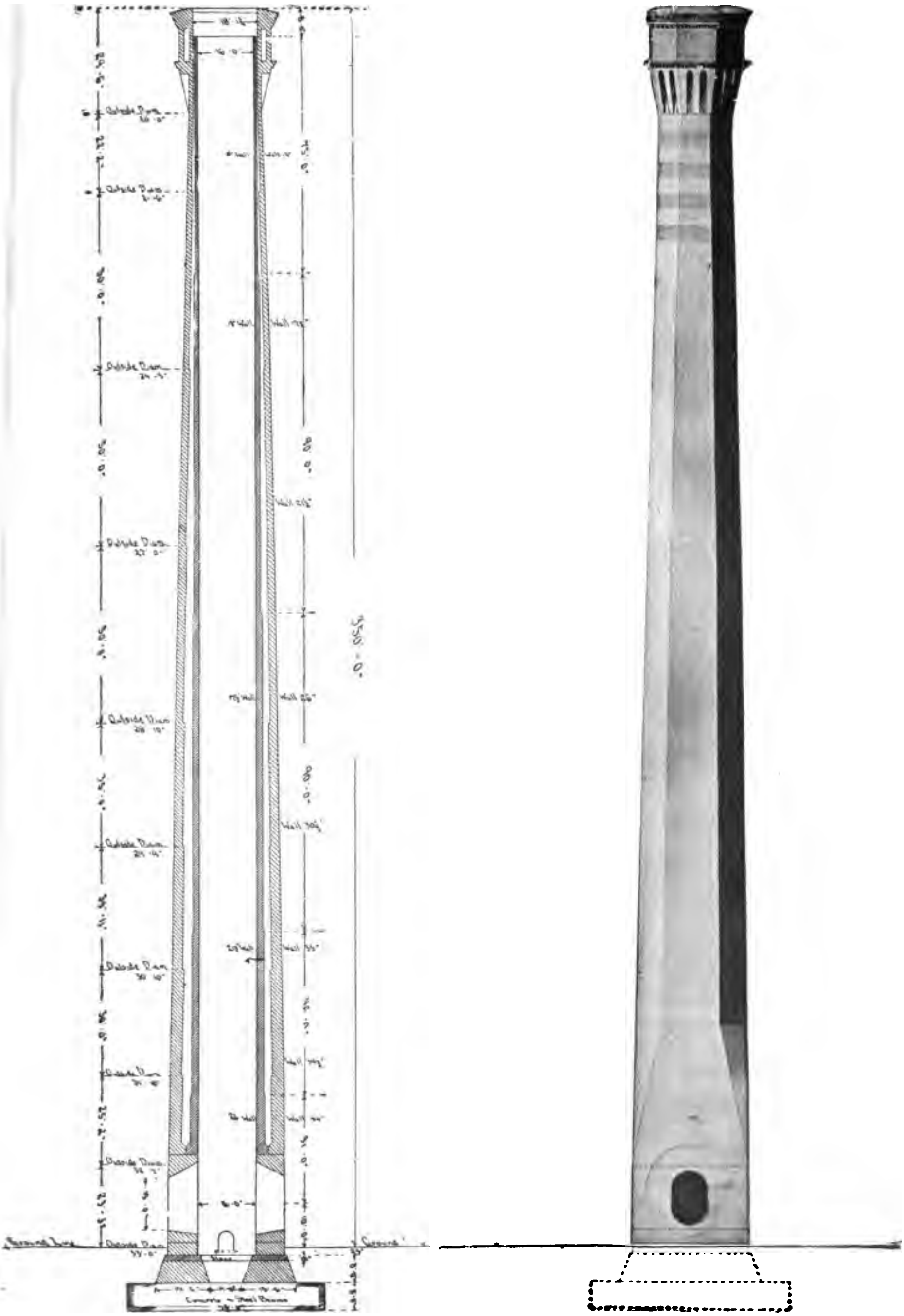
The *Denver Times* thus describes the Grant Smelting Company's chimney:

"The chimney of the Grant Smelting Company, designed by W. J. Scanlon, is the most marvellous construction of the kind in the world and the highest in the United States.* Its dimensions are as follows: It commences with a gravel foundation 8.4 feet high and 58 feet square, composed of Dikerhoff cement, containing from one to six parts of broken stone and sand. Barney Currigan had charge of the cement work.

"On top of this cement foundation the brickwork starts, 40 feet square at the base, and tapers to 35 feet at a distance of 7 feet from the base. On the top of this level there are two courses of Fort Collins stone 9 feet thick, bedded in cement mortar, the stonework being the grade line from which the chimney proper starts. The base of the chimney from here is 33 feet square, and it continues to the height of 352 feet 3 inches, diminishing 13 feet from the bottom to the top. The octagonal corners are not built on an inclined plane as usual. They are curved, with a prominent outside curve of about three feet. This was so constructed in order to obviate an optical delusion through the use of a centre line, by plumbing down to the centre, which was established by bedding plate in the centre of the chimney. A 15-pound bob was used for this purpose, with as fine a line as would carry it. Plumb rules were changed every ten feet, with curve established on the rule to carry up from one measurement to the other and also measured out from centre line every ten feet and came out on top within a fraction of the size required.

"The chimney has a flue of 16 feet in the clear, and walls 8 feet 6 inches thick, which extend to the top of the racking. At this level start two walls with a space between of 2 feet; the outer wall is 4 feet thick, and the core wall 2 feet 6 inches thick. The space between these walls of 2 feet extends to the top of the chimney, to the open air, and the outer wall for the last 100 feet is reduced to a 13-inch wall. The core wall is reduced to a 9-inch

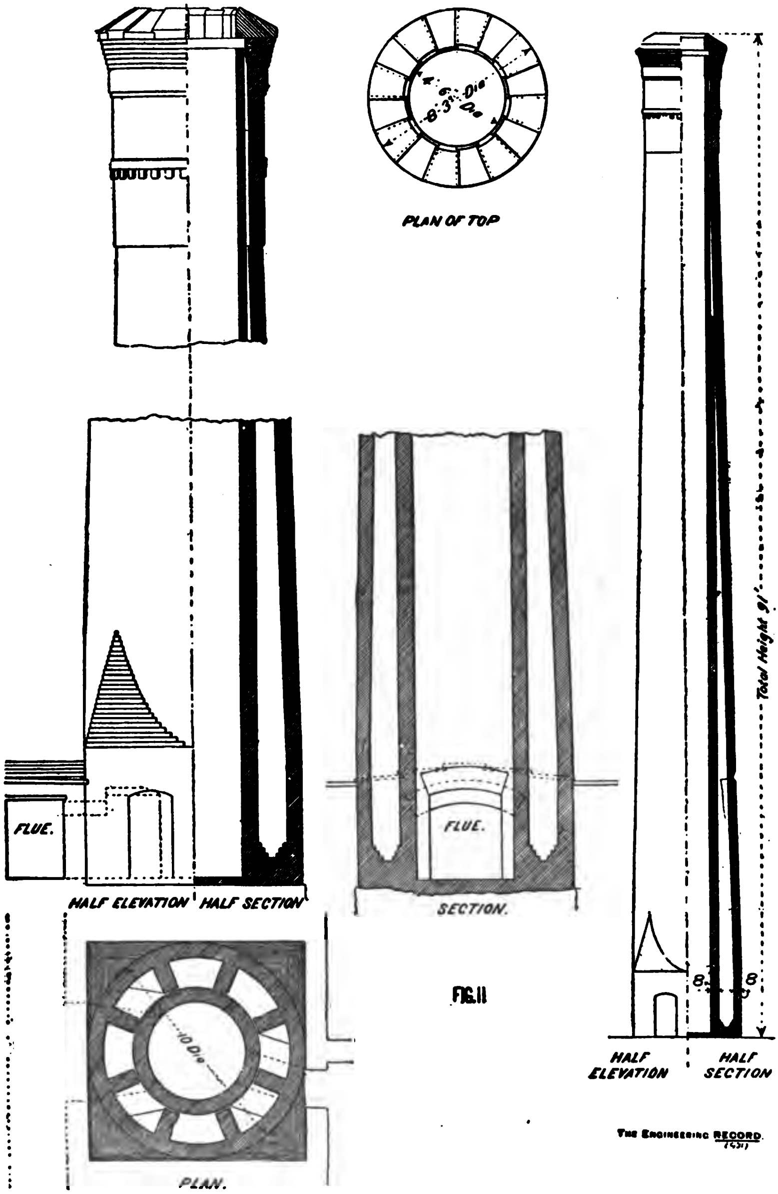
* In 1900 it was exceeded in diameter and height by the Metropolitan Traction Company's chimney, New York City, see p. 124 In 1901, in height by the Orford Copper Company's chimney, at Constable Hook, N. J., see p. 128.



"Helios."

ILLUS. No. 29.

Brick Chimney at the Omaha and Grant Smelting and Refining Works, Denver, Col.



ILLUS. No. 30.

CHIMNEY DETAILS, CHENEY BROTHERS' SILK MILLS, SOUTH MANCHESTER, CONN.

wall for the same height. From the 28-foot level the outer or main wall is separate from the core, or practically one chimney within the other.

"At intervals of every ten feet in each octagonal section there are buttresses carried from both walls with plates between. There are six rollers between each plate, so that the core can rise when the heat is great enough to cause expansion. This idea was to prevent the pressure from being sidewise.

"The top or finish, which is 30 feet high, with a projection of 5 feet 2 inches, is the heaviest one ever made in brick. It is banded by large iron circlets passing around the structure. These bands are placed over the inner walls with bolts running out, which fasten to angle irons that form the octagon. These angle irons are placed on the outer course of brick and built in solid with the best cement mortar.

"While being built it was kept level and the weight equalized the pull or pressure of going out on these irons. There were several sets of these irons. A cast-iron plate covers the entire top, with a trap-door which connects with an iron ladder built in the main wall on the inside next to the core wall.

"The weight of the structure is 8,000 tons, and its cost was $55,000. Over 2,000,000 pressed bricks were used in its composition. The brickwork was done by John Cook in 199 days. Twelve bricklayers worked on the first 100 feet, eight bricklayers on the next 100 feet, and six workmen on the remainder. The laborers were paid $7 a day, and the foreman received $8."

A Tall Brick Chimney.*

The largest chimney on the Pacific coast, 1892, the third in point of size in the United States, and the fourth in the world, is being built in San Francisco. The broad column of bricks is seen high above the roofs of the houses in its vicinity, and towers above every factory chimney in the city. The structure was put up by the Edison Electric Light and Power Company on Jessie Street near Third, in connection with a new building 75 feet front, 165 feet deep, and 52 feet high. The chimney is 175 feet above the pavement, and will rest on foundations, be-

* San Francisco *Chronicle*.

low the street level, of solid concrete 9 feet 8 inches thick, and 28 feet square. The interior diameter for the entire height is to be 12 feet. At the base the chimney has an exterior diameter of 18 feet 6 inches, and the outside diameter of the cap will be 14 feet. Inside, for a height of 73 feet, there will be a detached fire-brick lining with air-space between it and the interior surface of the chimney. The object of this lining is to protect the chimney from the expansion and contraction incident to the varying degree of heat. As the base is of concrete so is the topmost ring of the chimney. Laid in the artificial stone of the cap and intended to bind it firmly together, are seven hoops of one-inch wire rope. Between base and cap machine-made brick is used entirely, it being estimated that 275,000 bricks will be required to complete it. The concrete ring will be 4 feet deep, and the ornamental brick and concrete capital of the chimney will be 16 feet high. The only vertical openings in the chimney will be one about the level of the roof of the building in order to repair the fire-brick lining and to clean it, and one at the base through which to remove soot and ashes. From the roof an iron ladder will rise outside the chimney to the very top, so as to afford a means to repair the exterior when necessary. This ladder would, if connected by copper wires to the earth, form a lightning conductor. The latter has not been provided, however, it being considered unnecessary, as there is no instance in the history of the city of a chimney or building of any kind having been struck by lightning. The sole duty required of this enormous chimney is to afford a natural draught to twenty-eight boilers, which will furnish the motive power to six engines of 1,200 horse-power each, or 7,200 joint. The cost of this chimney is estimated at $10,000.

At Paterson, N. J., a great many of the old mill chimneys are built as follows: with square flue or core about 3 feet 4 inches square inside, and 75 feet high.

A chimney of the above dimensions has been built as follows:

Foundation of concrete, 9 feet by 9 feet by 4 feet deep; base of chimney, 7 feet 9 inches square; 12-inch wall tapering up 25 feet 6 inches; the next 19 feet 6 inches is 8-inch wall.

The core is 3 feet 4 inches square inside, with 8-inch wall running up and meeting the outer wall at 45 feet above the foundation, where the chimney is 6 feet square, above this the flue continues straight up, and the outside is drawn in to about 8 inches thickness of wall at the top.

A square cap of cast iron in four pieces is put on top, and bolted by inside flanges.

About 45,000 brick and 36 cubic yards of concrete entered into its construction.

The weight per square foot on foundation is 2.20 tons.

The weight per square foot on soil is 1.82 tons.

Air vents are placed in outside wall to let out the heated air from cavity between walls.

Some of these chimneys have had their top part lifted off by reason of the heat of the flue, and the flue and outer shell being run together, others have stood very well, probably because the fires have not been forced.

BRICK CHIMNEY AT THE PLANT OF THE STEINWAY ELECTRIC COMPANY, ASTORIA, L. I.

Flue, 8 feet in diameter.

Height, 140 feet above the ground.

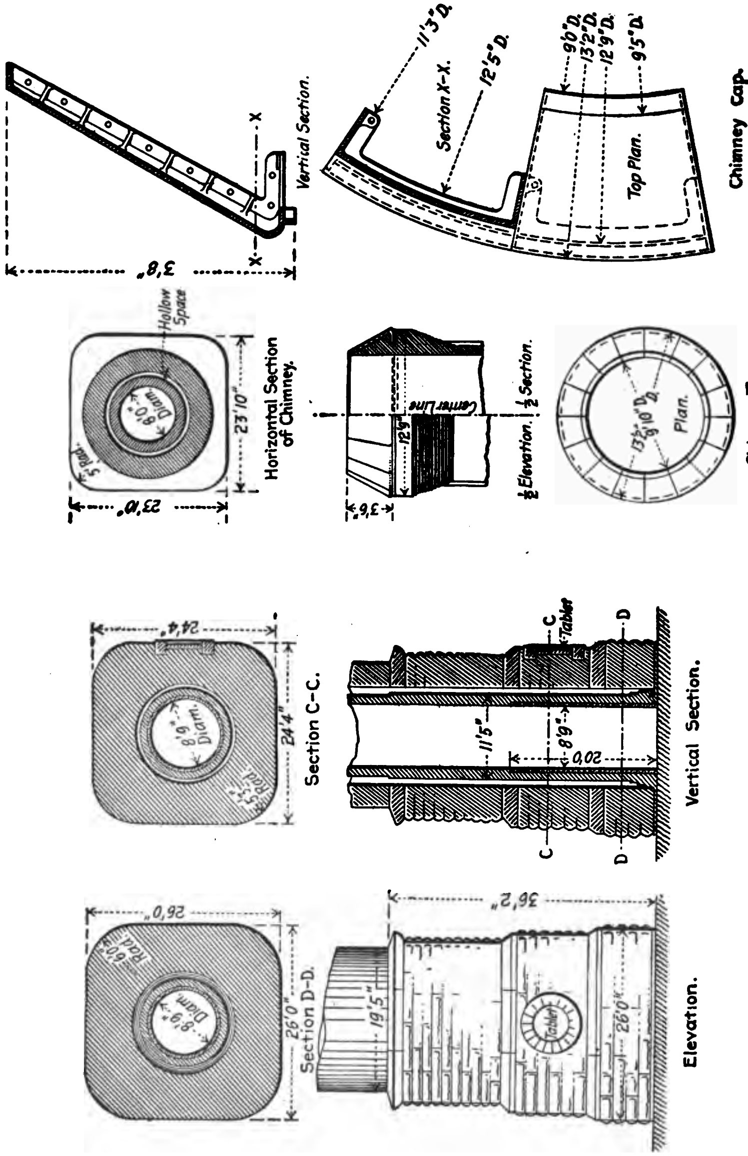
Fire-brick lining, 45 feet up from the bottom, 5 inches thick.

Core of chimney, 13 and 8 inches thick to within 50 feet of the top.

Outer shell, 32 inches thick at the bottom, reduced to 12 inches thick at the top.

ILLUS. No. 31.

STEINWAY ELECTRIC COMPANY, ASTORIA, L. I.



ILLUS. No. 32.
DETAILS OF BRICK CHIMNEY, IVORYDALE, O.

BRICK CHIMNEYS.

The Cambria Iron Company, Johnstown, Pa., in 1881 built two sizes of chimneys, which from the peculiar design were termed "Crinoline" chimneys.

One was 140 feet 6 inches high above base-plate, with a flue 7 feet 11 inches in diameter.

The other, 200 feet high above base-plate, with a flue 10 feet in diameter.

The prominent features of their design are:

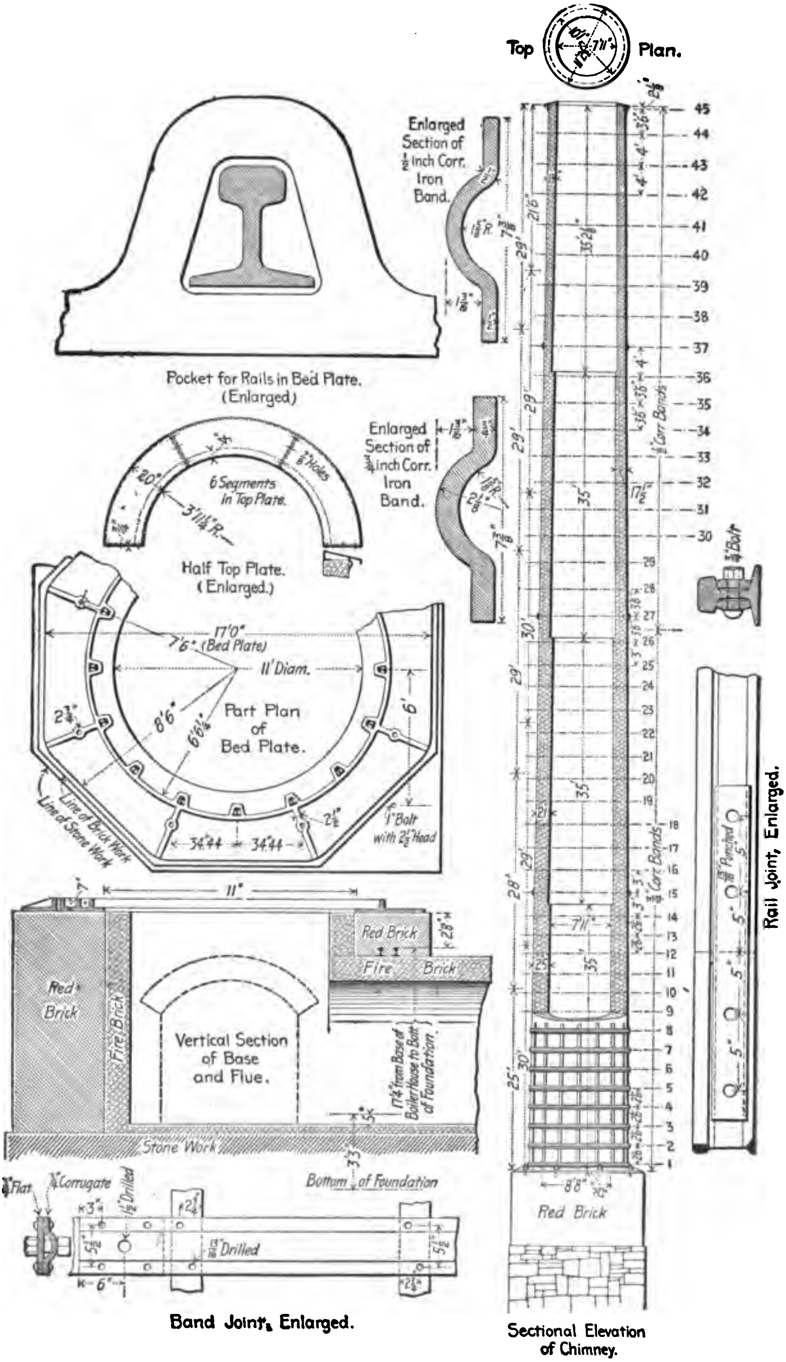
First.—Single-brick tube.

Second.—Cast-iron base-plate.

Third.—Steel rails set vertically in outer walls, with wrought-iron binders or hoops.

They have been in constant use up to the present time, and have proved themselves well fitted to the work for which they were designed.

Through the courtesy of Mr. Jos. Morgan, Chief Engineer of the works, the 140-foot chimney is pictured in detail on the opposite page.



ILLUS. No. 33.

THE CAMBRIA IRON COMPANY, JOHNSTOWN, PA.

Robert Kuntsman* gives the data for material for a brick chimney of 2,000 horse-power capacity, as follows:

Working capacity of chimney........	2,000	horse-power.
Depth of foundation	12	feet.
Height of chimney inclusive of foundation	205	feet.
Height of chimney from base line to top of cap	193	feet.
Height of cap from neck of shaft to top	14	feet 9 inches.
Effective height from inlet of boiler-flues	178	feet 3 inches.
Batter per foot on side walls $\frac{22}{100}$ inch outside, and.....................	$\frac{3}{100}$	inside.
External diameter of chimney at base line	17	feet.
Internal diameter of flue at base line.	8	feet.
External diameter at neck under cap.	10	feet 6 inches.
Interior diameter at extreme top.....	7	feet.
Thickness of outer wall under the cap	1½	brick, 12 inches.
Thickness of outer wall at section *CD*	2	brick, 16 inches.
Thickness of outer wall at section *EF*	2½	brick, 20½ inches.
Thickness of outer wall at section *GH*	3	brick, 24½ inches.
Thickness of outer wall at section (with inlet flue) *IK*.............	3	brick, 24½ inches.

Size of inlet flue from boilers, 9 feet by 4 feet 6 inches, with an area of 32 feet square.

Area of outlet on top of chimney..........	38.5 square feet.
Total weight of chimney, including foundation................................	1,588½ tons.
Total weight of brickwork, from base line upward	1,016½ tons.

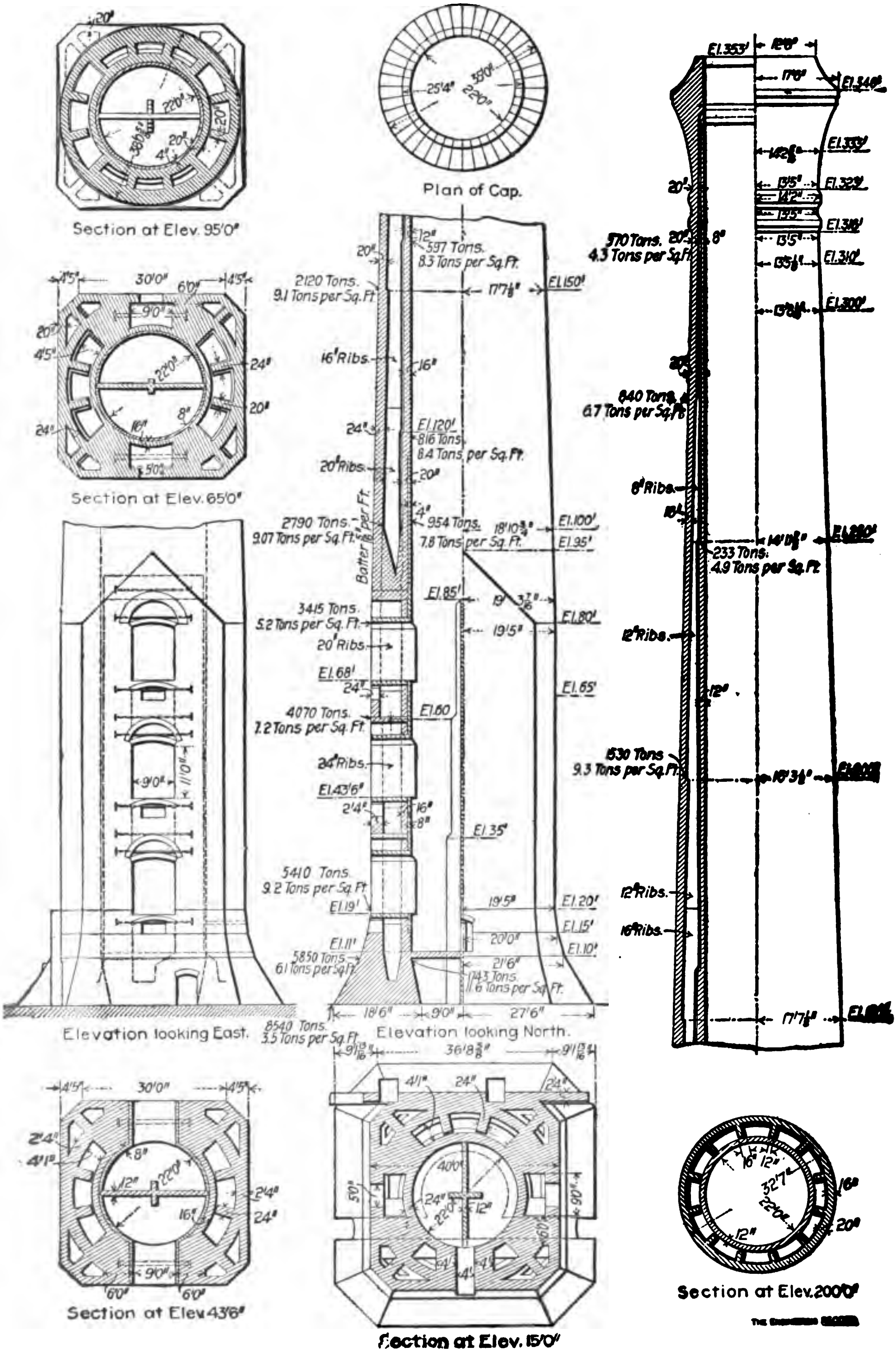
Load on concrete foundation 2.9 tons, or nearly 3 tons per square foot.

The load on the ground and distributed over an area of 1,370 square feet is therefore 0.86 ton per square foot.

It should not be difficult to arrive at the cost of this chimney at any locality if, according to local conditions, price of materials and labor are estimated from the quantities we have given.

It will require 390,000 brick.

* Brick, April, 1897.



ILLUS. No. 34.

Chimney Metropolitan Street Railway Power House, New York City.

BRICK CHIMNEY FOR THE METROPOLITAN STREET RAILWAY COMPANY,

NINETY-FIFTH STREET AND FIRST AVENUE, NEW YORK CITY.

Built in 1898.

The ground on which it is built was originally low ground, being covered at one time by the water of the East River, but had been filled in at a later period. A number of borings were made to determine the character of the strata below the earth and ash filling, averaging, respectively, about 10 and 15 feet in depth. Below the filling, blue clay or mud was found to an average depth of 35 feet, beach sand to about 45 feet, fine red sand from 45 to 55 feet, and, from this down, clay was present as far, at least, as 80 feet. Rock was found in one trial at a depth of 125 feet.

In building the foundations, which cover an area of about 85 feet square, the earth and ash filling were removed to a depth of 20 feet below the determined level of the station floor, taken as datum, and piles were driven to a depth of about 40 feet over the entire area. The piles are upon 2-feet 6-inch and 2-feet 3-inch centres, and a total of about 1,300 were driven by means of pile-drivers suspended from derrick booms. At a depth of 40 feet it was found that a 2,500-pound hammer falling 20 feet drove the piles about one inch, on an average. In driving the last 20 or 30 piles, the resistance was so great that they could not be driven over 15 feet. The piles were cut off 1 foot above the top of finished ground, or at a grade of — 19. An immense concrete block was laid upon them, 85 feet square and 20 feet thick, of 1, 3, and 5 Giant Portland cement-concrete. Cement mortar used in the brick-work was made of 1 part Giant Portland cement and 2 parts sand.

It is located close to the wall separating the engine and boiler rooms of the station, and divides the boiler room in two parts. Smoke flues lead from the boilers to the chimney from opposite directions, and as there are three stories in the boiler house upon which the boilers are to be installed, there

are six large openings to the chimney, two on each of the three floors. The chimney is built of two concentric shells, and the outer shell is stiffened by 12 interior longitudinal ribs projecting radially toward the inner shaft and leaving a clearance of $\frac{1}{2}$ inch. The inner shaft has a constant diameter of 22 feet, and the outer dimensions of the stack range from a square base, 55 feet on a side, to a neck of 26 feet 10 inches in diameter, 316 feet above. The cylindrical exterior of the chimney is given a batter of $3\frac{1}{8}$ inches in 10 feet, or 0.312 inches per foot.

The two shells rise from a common brick base resting on the concrete, and are practically a single structure up to a few feet above the smoke-flue openings. These openings are 24 feet 6 inches, one above the other, and 4 feet below the first opening, at the 15-foot elevation, the shaft is lined with an 8-inch thickness of fire-brick to a height of 90 feet, which is about 10 feet above the third-floor opening. Beyond this for 25 feet the fire-brick is only 4 inches thick, and from the 115-foot elevation upward the walls are of common brick. The weakening caused by the openings is overcome by the double-arch construction and the use of tie-beams of channel iron. A 12-inch brick wall, 85 feet high and provided with a buttress divides the lower part of the shaft into two parts, separating the two tiers of smoke-flue openings. The inner shell is built in five sections from the basal thickness of the wall, which is 24 inches, to an 8-inch wall at its top, 340 feet high. The outer shell, as to thickness, ranges from 28 to 16 inches. The fourth section, from the 200 to the 280-foot elevation, is 16 inches thick, as shown, and the wall thickness then becomes 20 inches. The successive gradations of thickness up to this point conform to the requirements of the limiting stresses allowed, but the enlargement is made, aside from providing for the coping, to bring the two shells in closest proximity, so that both may assist in resisting lateral strains. The gap between the two shells near the top of the chimney is protected with an apron of sheet-iron 4 feet wide and provided with a flange at the top imbedded in the brickwork. The top of the chimney is protected with an iron cap formed of 40 cast-iron sectors, bolted one to the other.

They envelop the top brickwork, and are anchored by vertical tie-rods to an annular steel ring about 28 inches in diameter imbedded in the brickwork about 14 feet below the cap. Ten lightning-rods point upward 6 feet above the top of the chimney, and are connected to a copper ring, which is provided with two descending conductors of copper, each 1 by $\frac{3}{16}$ inch in cross section. These conductors are also connected to the iron top. Two other steel rings are also encased near the top, one about 342 feet and another about 313 feet from the base, to prevent any tendency to disintegration resulting from incipient cracks.

The chimney for the station, now practically completed, stands 353 feet above its foundation, and it is, therefore, the tallest chimney in the United States.* Its internal diameter is 22 feet, and in that dimension it is the largest brick chimney in the world. Rankine's formula was used in determining its capacity, and in designing the chimney it was assumed that the wind-pressure would be equivalent to a pressure of about 40 pounds per square foot of diametrical area. The total weight of the chimney is 8,540 tons, and 3,400,000 red bricks were used in the construction.

The drawings show at various elevations the total weight supported, and the corresponding stress per square foot of sectional area. The pressure intensity of the outer shell is on the average greater than that in the interior shaft, being about 9 tons per square foot. The unit load at the concrete base is only 3.5 tons for the whole weight of the chimney.

The chimney was designed by the Engineering Department of the Metropolitan Street Railway Company.—*Engineering Record*, vol. xxxix., p. 53.

* In 1901 it is exceeded in height only by the chimney of the Orford Copper Company, Constable Hook, N. J., which is 360 feet high, see p. 128.

ILLUS. No. 35.

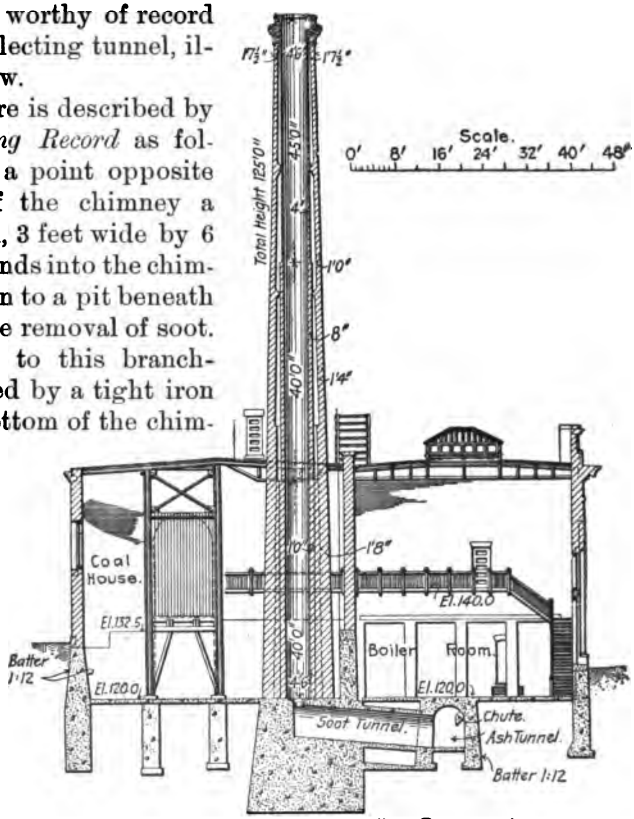
BARBOUR FLAX SPINNING CO., GRAND STREET, PATERSON, N. J.

Flue, 6 feet diameter. Height, 175 feet.

THE CHESTNUT HILL PUMPING STATION CHIMNEY.

This chimney, built by the Metropolitan Water Board, Boston, Mass., 125 feet high with a flue 4½ feet in diameter, has a feature worthy of record in its soot-collecting tunnel, illustrated below.

This feature is described by the *Engineering Record* as follows: "From a point opposite the centre of the chimney a branch tunnel, 3 feet wide by 6 feet high, extends into the chimney foundation to a pit beneath the flue, for the removal of soot. The entrance to this branch-tunnel is closed by a tight iron door. The bottom of the chimney is contracted into the form of an inverted truncated cone, whose smaller diameter is 24 inches.



Transverse Section through Boiler Room and Coal House.

"This opening is closed by a door made of two semi-circular ¼-inch wrought-iron plates, arranged to revolve about a 1½-inch diameter horizontal steel shaft at the diameter of the circle. By means of pulleys and a chain passing through the walls of the chimney the two leaves of this door can be dropped simultaneously to dump the soot and then be closed again from the coal-house without entering the flue." By this arrangement the chimney draft is not interfered with while removing the soot.

ORFORD COPPER COMPANY'S CHIMNEY.

This radial-brick chimney, 360 feet high, consisting of a single shaft, is now being built (1901) at Constable Hook, N. J., for the Orford Copper Company, to elevate the gases from chemical reactions so high as to be the cause of no harm to the people of the neighborhood.

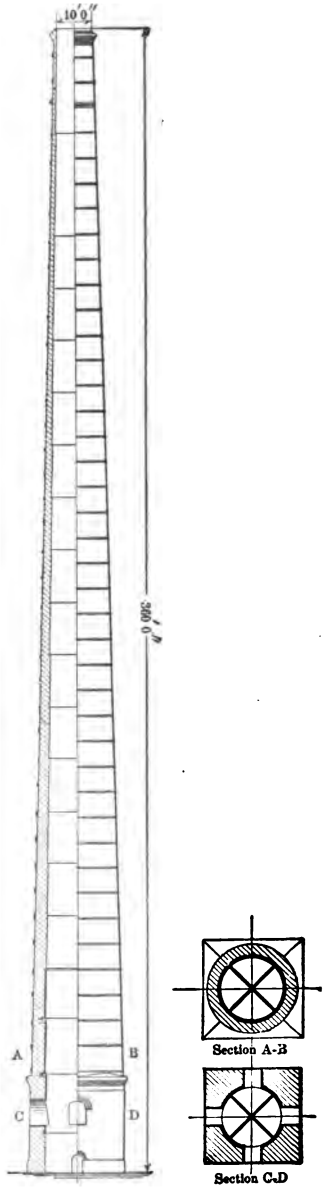
With an internal diameter of 20 feet at the base, and 10 feet at the top, a square exterior for 30 feet above the foundation, the balance of the height is circular in cross-section to the top.

The square portion of the shaft is built of ordinary red brick, the circular part of radial brick (custodis). These radial bricks vary in size from 12 inches radial length at the base, laid in five concentric rows, to 11 inches at the top, in one row, by 4 inches thick (or high).

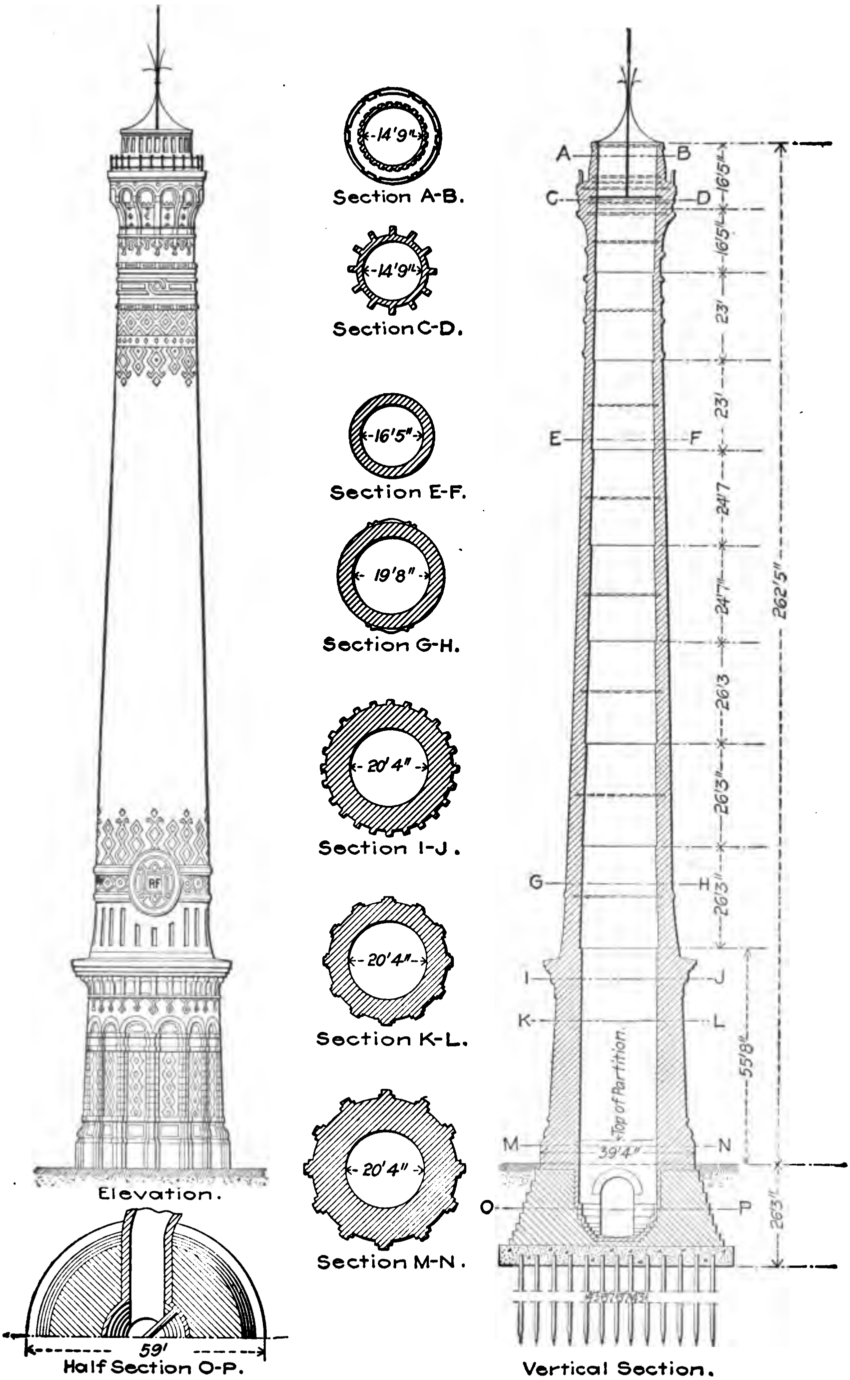
The circular portion is 46 inches thick at the 30-feet elevation, its outside base a taper of 3 inches in 10 feet, the inside being offset 2 inches every $16\frac{1}{2}$ feet. $3\frac{1}{2} \times \frac{5}{16}$-inch iron bands encircle the brickwork every 8 feet in height, to the cap, which also is made of moulded brick.

The fire-brick lining, 42 feet high, intended to resist a temperature of 1,500° Fahr., is divided into three parts or sections, each carried on corbels at their bottom, and leaving an air-space of 2 inches between the lining and shell. Two partitions, forming an X, deflect the gases upward from four inlets.

The estimated weight of the chimney is 3,475 tons, giving a load of 5.57 tons per square foot on an area of 624.4 square feet at the foundation level.



ILLUS. No. 36.



ILLUS. No. 37.
CHIMNEYS AT THE PARIS EXHIBITION.

BRICK CHIMNEYS AT THE 1900 PARIS EXHIBITION.

A pair of chimneys of white brick, with decorations of terra-cotta, and brick of various colors, consisting of a single shell, 262 feet 5 inches above the ground, with a flue 14 feet 9 inches at the smallest diameter, were built on the Exposition grounds for furnishing draft to the various steam-boilers.

The sub-foundation of concrete, 59 feet in diameter × 5 feet thick rests on 133 oak piles, 12 inches diameter × 23 feet long, driven in circular rows by a hammer weighing 2,650 pounds; above this a stone foundation is built up to the ground-level or nearly so.

Two flues enter each chimney, a diaphragm being built in the chimney a short distance to keep the inlets separate and distinct.

The shaft proper consists of a twelve-panel pedestal 52½ feet high, and a highly ornamented shaft bound together by 0.43 × 4.75-inch flat iron bands fifteen in number, bolted together and embedded in the masonry.

An inside ladder provides for access to the top, and a copper-pointed lightning rod at the top, grounded to drainage and waste pipes, is to take care of lightning discharges.

The thickness of the wall at the top is 14 inches to a maximum of 4 feet 5 inches at the cap, 5¼ feet at base of cylindrical part and 6 to 9½ feet in the pedestal.

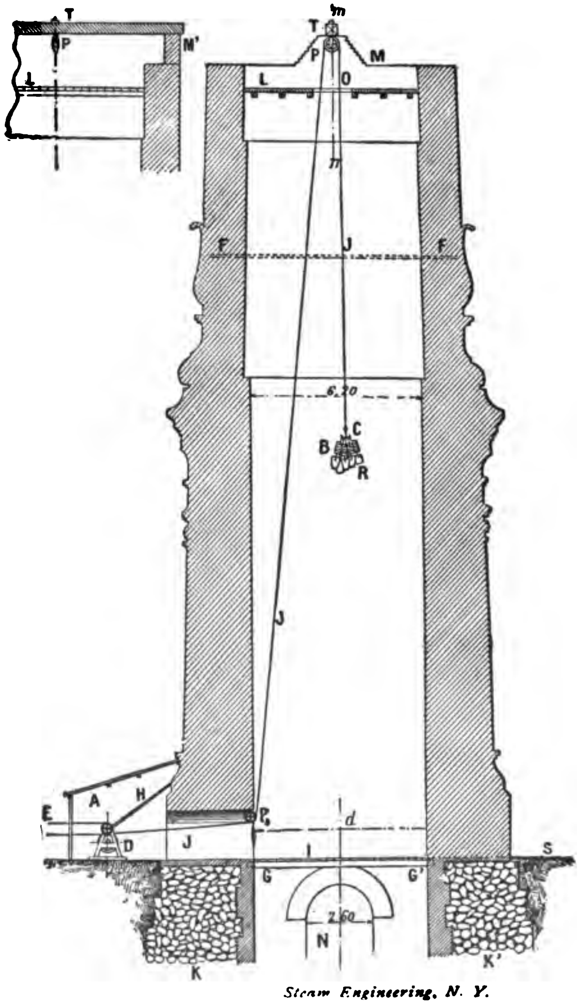
The concrete was 2 parts stone, 1 part mortar, which mortar was 500 pounds Portland cement to one cubic yard of sand. The mortar for the shaft was composed of 1 part hydraulic lime to 2 parts of sand.

The first 92 feet was built from outside scaffolding, above which height a fir-plank platform inside the shaft, from which was hung a platform-car with a capacity of upward of 3,300 pounds.

This timber floor was raised every 20 feet, a five horse-power engine did the hoisting, the apparatus being shown in detail by the cut on page 131.

Three thousand cubic yards of brickwork, and 1,300 cubic yards of other masonry were used in the work.

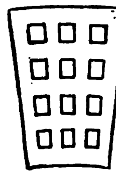
For more complete description and illustration of these two chimneys see *Engineering Record, Steam Engineering, Genie Civil and Zeits. d. Verein. Deutsch. Ing.,* all of 1890.



ILLUS. No. 38.

ALPHONS CUSTODIS, DUSSELDORF ON RHINE,

as well as other builders, have built a great many round chimneys, using a special moulded radial brick. The brick "are made from pure, thoroughly consistent clay and pressed with water," burned at a heat of not less than 1,500° Fahr. A smooth surface, and a surface which is less porous than is the case with common brick, is thus obtained. These brick are perforated in one direction—vertical, leaving an air-space from top to bottom, which acts as a sort of jacket to the flue, but is not continuous, as the mortar at each joint acts as a separator.



This design of brick adds to the stability of the chimney, by virtue of the less number of joints subject to the weather, and also the better bond which Mr. Custodis says he secures.

Comparative experiments at the Royal Testing Station for Building Materials in Berlin, with perforated and unperforated chimney bricks, show the following:

1. In unperforated bricks the material possessed the extraordinary compressive strength of 350 kilos per square centimetre (= 4,978 pounds per square inch).

2. In perforated bricks made of the same raw material, the compressive strength was even somewhat greater, 354 kilos per square centimetre (5,035 pounds per square inch), although the sectional area of the holes was included as surface.

3. The adhesive power of cement-mortar used with unperforated bricks amounts to 1.53 kilos per square centimetre ($21\frac{3}{4}$ pounds per square inch), while with perforated bricks it amounted to 4.33 kilos per square centimetre ($61\frac{1}{2}$ pounds per square inch), or about three times as much.

Illustration No. 39 shows a chimney built in the manner just described and of radial brick.

As it is generally found desirable in a brick chimney to have a central core or flue lined with fire-brick to protect the chimney itself from being destroyed by the varying temperatures within, Mr. Custodis uses the sectional method of building the lining, giving it a uniform thickness, which allows a

By courtesy of *The Staten Islander*, New Brighton, S. I

ILLUS. No. 39.

Orford Copper Company, Constable Hook, N. J.
Designed and built by Alphons Custodis Chimney Construction Company.
Height, 360 feet; inside diameter of flue at top, 13 feet.

section at a time to be repaired; each section can expand vertically according to the heat each section receives; on account of the small lining thickness necessary, this method is very economical.

Because of the superior strength of the bricks used and wall thickness used the diameter at the base of any chimney can be much less than for red brick chimneys, less land occupied, and a less unit load on the foundation.

Chimneys of this type built in the United States, which are over 150 feet high, are in part located as follows:

Bethlehem Steel Company, South Bethlehem, Pa.
(2) 175 feet by 8 feet inside top diameter.
(1) 175 feet by 9 feet inside top diameter.

Yorkville Independent Hygeia-Ice Company, New York City.
Stack 190 feet by 7 feet 6 inches inside top diameter.

New York Shipbuilding Company, Camden, N. J.
200 feet by 8 feet 6 inches inside top diameter.

Great Northern Paper Company, Millinocket, Me.
235 feet by 12 feet inside top diameter.

Manhattan Railway Company, New York City.
(4) 278 feet by 17 feet inside top diameter.

Orford Copper Company, Constable Hook, N. J.
360 feet by 13 feet inside top diameter.

[illegible]

1. [illegible]

[illegible] walls.

[illegible]

[illegible]		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Exterior diameter at base is 1[illegible] feet 6 inches; batter, [illegible] [illegible] in [illegible] from the bottom to 6 feet from the top, then straight. Space between walls 16 inches at bottom, [illegible] to nothing at the top of core wall.

The exterior is of red brick, except a lining of fire-brick for [illegible] feet up from the bottom.

2. Montreal [illegible] Street Railway Company, William Street Power House.

The chimney (1894) is the highest in Montreal, 190 feet high above the fire grate, and with a flue 9 feet diameter, gives a draft of $1\frac{1}{2}$ inches of water.

The chimney is built with double walls, and the square pedestal base is 18 feet square outside.

Three thousand horse-power of Lancashire double-flue boilers are connected to it.

3. Mechernich Lead Mining Company. Flue, 9 feet 10 inches; height, 440 feet 6 inches; foundation of dressed stone, 36 feet square by 11 feet 6 inches high.

The base, a cube of 32 feet 9 inches, and the octagonal plinth of the shaft are both built of annular kiln bricks.

The circular shaft is formed of radial bricks, it is 24 feet 6 inches outside diameter, and 11 feet 6 diameter inside at base; at the top it is 11 feet 6 inches outside and 9 feet 10 inches inside diameter.

LIST OF BRICK CHIMNEYS.

1. At Knoxville, Tenn. Illustrated in *Engineering News*, November 2, 1893.

Flue, 6 feet diameter; 120 feet high; double walls.

TABLE No. 25.

EXTERIOR WALL.		INTERIOR CORE.	
Height, feet.	Thickness, inches.	Height, feet.	Thickness, inches.
20	21	35	13½
30	17	35	8½
30	13	29	4
40	8½	21	0

Exterior diameter at base is 15 feet 6 inches; batter, $\frac{7}{16}$ inch in 12 inches from the bottom to 8 feet from the top, then straight. Space between walls, 16 inches at bottom, diminishing to nothing at the top of core wall.

The interior is of red brick, except a lining of fire-brick for 20 feet up from the bottom.

2. Montreal (Can.) Street Railway Company, William Street Power House.

This chimney (1894) is the highest in Montreal, 190 feet high above the fire-grate, and with a flue 9 feet diameter, gives a draft of 1⅛ inches of water.

The chimney is built with double walls, and the square pedestal base is 18 feet square outside.

Three thousand horse-power of Lancashire double-flue boilers are connected to it.

3. Mechernich Lead Mining Company. Flue, 9 feet 10 inches; height, 440 feet 6 inches; foundation of dressed stone, 36 feet square by 11 feet 6 inches high.

The base, a cube of 32 feet 9 inches, and the octagonal plinth of the shaft are both built of annular kiln bricks.

The circular shaft is formed of radial bricks, it is 24 feet 6 inches outside diameter, and 11 feet 6 diameter inside at base; at the top it is 11 feet 6 inches outside and 9 feet 10 inches inside diameter.

ILLUS. No. 40.

OLD COPPER WORKS CHIMNEY AT BELLEVILLE, N. J.

4. New Sessions Foundry, Bristol, Conn.

Flue, 42 inches diameter by 110 feet high; circular, 6 feet diameter at top, 10 feet diameter at base, set on an 11-foot square bed at ground. Three 150 horse-power Heine boilers connected to it.

5. Passaic Print Works, Passaic, N. J.

Flue, 9 feet diameter by 200 feet high; cost, $15,000; built by Flynt Building and Construction Company.

This chimney has three batters in the height.

Eighteen 6 feet diameter by 18 feet long horizontal tubular boilers are connected to it, with a total of 760 square feet of grate.

6. Fall River Iron Company.

Flue, 11 feet diameter by 350 feet high; diameter outside at base, 30 feet; diameter outside at top, 21 feet.

Foundation of granite, 55 feet by 30 feet by 16 feet deep.

Required 1,700,000 brick, 2,000 tons stone, 2,000 barrels mortar, 1,000 loads of sand.

Estimated cost, $40,000.

7. Dundee Chemical Works, Passaic, N. J.

Circular, 175 feet high, 14 feet square at bottom; laid up in cement.

Used to get rid of gases from chemical reaction at a high altitude; cost $7,000.

Since it was built it showed several large cracks from the top one-third the way down and has been rebuilt; iron bands being placed around the outside to retain the brick.

8. Merrimack Manufacturing Company, Lowell, Mass.

Flue, 12 feet diameter; 282 feet high; round pedestal, cost $18,500; load on foundation 4.8 tons per square foot.

The foundation is 30 feet in diameter of dressed granite blocks laid in clear Portland cement; core was laid in lime and sand mortar; the outside shell was laid in lime, cement, and sand.

9. Municipal Lighting Plant, Frankfort-on-Main, Germany.
Flue, 7 feet diameter; 164 feet high.
Supplies draft for 12 internally fired boilers with single furnace, and four Galloway tubes.
Boilers, 82 inches diameter by 28.8 feet long; 925 feet of heating surface each.
10. Port Dundee, Glasgow, Scotland.
488 feet high. Cost, $40,000.
11. Townsend, Glasgow, Scotland.
454 feet high.
12. Tennant & Company, Glasgow, Scotland.
434 feet 6 inches high.
13. Crossley's, Halifax, England.
381 feet high. Octagonal, stone.
14. Dobson & Barlow, Bolton, England.
13 feet 2 inches diameter; 367½ feet high.
15. Brooks's Fire-clay Works, Huddersfield, England.
306 feet high. Circular, brick, and stone.
16. Mitchel Brothers, Bradford, England.
300 feet high. Octagonal, stone.
17. Edinburgh Gas Light Company, Edinburgh, Scotland.
Flue, 12 feet diameter; 264 feet high. Cost, $25,000. Circular, stone, square pedestal.
Load on bottom or soil is 2.5 tons per square foot.
18. West Cumberland Hematite Iron Works, England.
251 feet high. Circular, stone.
19. Amoskeag Mills, Manchester, N. H.
Flue, 10 feet diameter; 250 feet high. Circular, brick.
20. Washington Mills, Lawrence, Mass.
Flue, 10 feet diameter; 250 feet high. Circular, brick.
21. Tremont and Suffolk Mills, Lowell, Mass.
(1) Flue, 10 feet diameter; 250 feet high. Circular, brick.
22. Tremont and Suffolk Mills, Lowell, Mass.
(2) Flue, rectangular, oblong, brick. Height, 238 feet.
23. Lower Pacific Mills, Lawrence, Mass.
Flue, 8 feet diameter; 214 feet high. Circular, brick.
24. Edison Electric Illuminating Company, Paterson, N. J.
(1) Old chimney; 200 feet high. Octagonal.

25. Edison Electric Illuminating Company, Paterson, N. J.
(2) New chimney; 225 feet high. Circular.

26. Newland's Mills, Bradford, England.
Flue, 9 feet diameter; 260 feet high.
Load on bottom on soil, 4.5 tons per square foot.

27. McCormack's Reaper Works.
Flue, 6 feet 8 inches diameter; 160 feet high.
Load on soil, a dry hard clay, 1.8 tons per square foot.

28. Queen Lane Pumping Station, Philadelphia, Pa.
Flue, 12 feet diameter; 200 feet high.
Foundation, 37 feet square by 24 feet deep.

29. Tweedvale Manufacturing Company.
Flue, 4 feet diameter; 125 feet high.
Foundation, 19 feet square by 9 feet deep.

30. Grosvenordale Company, North Grosvenordale, Conn.
Flue, 5 feet diameter; 150 feet high. *Power*, December, 1897.

31. New Chester Water Company.
Flue, octagonal; area, 2,430 square inches; height, 105 feet. Lined with fire-brick 20 feet up above the opening for breeching.
Furnishes draft to five 60 inch diameter by 16 feet horizontal tubular boilers.—*Engineering Record*, vol. xxv.

32. Chicago City Railway Company.
14 feet diameter of flue by 208 feet high. Top round; base square.
Foundation, 50 feet square; 16 feet deep.
For twenty-four 78 inches by 20 feet horizontal tubular boilers. John Mohr & Sons.—*Power and Transmission*, May, 1897.

33. Akron, Ohio, Street Railway and Illuminating Company.
Octagon exterior, brick, round flue; 72 inches diameter; 130 feet high.

34. Brisbane, Queensland, Australia, Electric Power Plant.
Brick chimney, 7 feet diameter of flue by 15 feet high, for 2,400 horse-power B. and W. boilers; 1,200 of which is now in.

CHAPTER VIII

CHIMNEY PERFORMANCES.—SPECIAL TYPES.—STRAIGHTENING CHIMNEYS.—FLUES

CHIMNEY PERFORMANCES.

Brick chimney, Dwight Manufacturing Company, Chicopee, Mass.

Flue, 4 feet square by feet high.

Burned through it 1,587.8 pounds anthracite coal per hour; burned through it 1,459.0 pounds combustible per hour; draft 0.45 inch.

Horse-power developed in boilers, 460.9.

Equivalent evaporation per pound of combustible from and at 212° = 11.17 pounds.

Coal burned per hour per square foot of grate = 10.97 pounds.

Boilers connected to chimney: 4 vertical Corliss boilers 8 feet diameter, and 2 vertical Corliss boilers 10 feet diameter.

A chimney 80 feet high, flue 42 inches diameter, has been found to cause sufficient draft for a rate of combustion of 120 pounds of coal per hour per square foot of area of chimney, or if the grate area is to the chimney area as 8 to 1, a combustion of 15 pounds of coal per square foot of grate per hour, or a total combustion of 1,154.4 pounds of coal per hour.—Kent: "Transactions of the American Society of Mechanical Engineers," vol. vi.

The author's Table No. 10 gives the capacity of this chimney as 1,128 pounds.

A chimney 92 feet high, flue 50 inches diameter.

Area of 13.63 square feet; area of flue inlet = 13.12 square feet; area of grate 48 square feet, with an air space of 21

square feet, with a temperature of chimney gases of 609° Fahr., caused sufficient draft for the combustion of 1,179 pounds of free bituminous coal per hour.—Gale: "Transactions of the American Society of Mechanical Engineers," vol. vi.

The author's formulæ, Table No. 10, gives the capacity of this chimney as 1,141 pounds.

"Transactions of the American Society of Mechanical Engineers," vol. xv., p. 610, says: "Three hundred boiler horse-powers were connected to a chimney 72 inches diameter of the flue by 125 feet high, with poor results; but when chimney was changed to 42 inches diameter by 125 feet high, the boilers worked much better."

The author's Table No. 8 gives the capacity of the latter chimney as 351 boiler horse-power.

Steel chimney, 38 inches diameter by 110 feet high, over a Cahall vertical boiler at Armstrong Cook Co's. Works, Pittsburg, Pa.

Tests by J. M. Whitham. Coal, nut and slack, from Sandy Creek Mine, near Pittsburg, Pa. Efficiency test, 917 pounds of coal burned per hour.

According to the author's formulæ, this chimney capacity is 1,073 pounds; capacity test, 1,702 pounds of coal burned per hour.

Brick chimney, 8 feet diameter flue by 175 feet high, Armour & Co's. plant, Kansas City, Mo.

Coal—Ardmor, Mo., bituminous Mine-Run coal. Tests by F. G. Gasche, M.E.

Flue temperature, 580° Fahr.; out-door temperature, 80° Fahr. (approximate).

Draft in chimney, 0.68 inch of water.

Boiler horse-power is 1,167.

Coal burned per hour, 7,198 pounds.—*Power*, August, 1897.

Steel chimney, 4 feet diameter flue by 100 feet high. Reid & Barry, Passaic, N. J.

Attached to two boilers rated at 250 horse-power each, with

a total of 104.76 feet of grate-surface, gave the following results with different coals used under boiler:

	Anthracite buck. coal.	Bituminous lump coal.
Temperature of external air..................	45° Fahr.	42° Fahr.
Temperature of gases at base of chimney......	372° Fahr.	427° Fahr.
Coal bufned per hour, total dry..............	1,902 pounds.	1,865 pounds.
Force of draft in inches of water.............	0.48	0.55
Theoretical draft, we might look for.........	0.556	0.624
Barometer..................................	30.35 inches.	29.9 inches.

Natural draft was used, and the coal burned in both cases coincides with what might be looked for from the author's tables.

An old chimney, 67 feet high, with internal diameter of 19.6 inches to 13.8 inches, and with a total distance from fire to chimney of 98 feet, was taken down, and a new chimney with an intended total distance from fire to outlet of 95 feet, and a minimum internal diameter of 25.5 inches was planned; when the chimney had gone up 39 feet it was tried, already there was a great improvement on the old chimney; again at 46 feet it was still better, and at 52.5 feet the draft was excellent, and there was an economy of 15 to 20 per cent. in fuel. The chimney was therefore finished at that height. Ramdohr of Gotha confirms this, and recommends a uniform internal diameter as being more rational and as protecting the brickwork from the hot and rapid axial stream.—*Journal du Gazet l'Electricitat,* 1897.

A steel chimney, 110 feet high, with flue 42 inches diameter, attached to a boiler rated at 250 boiler horse-power, with 57 square feet of grate-surface, under test, when starting the plant with outside air quiet, and with a temperature of 40° Fahr., showed the following results:

Temperature of gases at base of chimney..	300° F.	445° F.	525° F.	575° F.
Force of draft in inches of water.........	0.36	0.46	0.52	0.56

—Geo. H. Barrus, 1894.

OFFICE-BUILDING CHIMNEYS.

Tall office-building chimneys in the large cities are often made of steel, circular in shape, and placed in the ventilating shaft in many instances to assist it in the purifying of the air throughout the building; these chimneys need no special strength, being braced to the walls of the shaft and easy to support.

The metal and riveting should be proportioned as in guyed steel chimneys.

Other chimneys are of brick in office buildings built like any house chimney, while others of steel are placed in the "open air" or light shaft, as the chimney of the Manhattan Life Building, New York City; this is 4 feet 6 inches diameter of flue by about 360 feet high, and is secured to the wall by wrought-iron straps. It furnishes draft to three internally fired Scotch boilers, with 1,620 square feet of heating surface each, total 4,860 square feet.

The first record of steel chimneys in use in tall office buildings, is that at "the Fair," Chicago, Ill., built in 1890–91, which is described as follows:

Diameter of outside of 4-inch tile lining is 6 feet 9 inches.

Diameter of flue in clear at fire-brick lining, 5 feet 9 inches.

Diameter of flue in clear at tile lining, 6 feet 1 inch.

Height of chimney, 172 feet 6 inches.

Starting from the basement floor, the chimney rests on a brick base $2\frac{1}{2}$ feet high; at the base two 4 by 4 by $\frac{2}{16}$-inch angles are riveted, one inside and one outside of the $\frac{1}{4}$-inch shell, and they in turn rest on a cast-iron ring $1\frac{1}{4}$ by $8\frac{1}{4}$ inches in section, through all of which the $\frac{3}{4}$-inch anchor or foundation bolts pass; thickness of shell is $\frac{1}{4}$ inch throughout, the first 40 feet is lined with fire-brick 6 inches thick, above which a 3 by 4 by $\frac{7}{16}$-inch angle-iron is riveted thus $\overset{3''}{\rceil}\,4''$ to the shell, and similar ones above this about every 15 feet, which carry the 4-inch tile-lining which goes to the top of shell.

The cap is made of $\frac{1}{4}$-inch steel shaped like an inverted U, fitted outside of shell, and inside of tile riveted to shell.

The chimney is braced to the building by two 3 by 3 by $\frac{1}{2}$-inch

angles fastened to columns. Space around the chimney is utilized for purposes of ventilation.—*Engineering Record*, vol. xxix., p. 157.

REMOVING BRICK CHIMNEYS.

A brick chimney octagonal in section, 135 feet high, external diameter 12 feet, base 17 feet square by 16½ feet high, with walls 3 feet thick, at a brick works in Lörincznyaralo, Hungary, was blasted by Lieutenant-Colonel Tangl of the army and his men.

Bricks were removed for about three feet in height, directly above the base, leaving two openings—one in front, one in the rear; this work being done by four men in nine hours.

The structure was to fall to the ground close to the base on account of nearby buildings.

A mine of 15 pounds of "ecrasite" was placed in one opening, and two of 11 pounds in the other, all placed 10 inches above the base in order to spare it.

They were fired simultaneously, and the chimney fell in a bottle-shaped mass just away from the base, occupying a length of 190 feet, height of 10 feet, and the greatest width was 56 feet at 66 feet from the base.

Observers did not feel the rush of air, but in the direction of the fall windows were broken at a distance of 260 and 500 feet.—*Engineering*, p. 658, 1898.

CAST-IRON OFFICE-BUILDING CHIMNEY.

University Block, Syracuse, N. Y., eleven-story steel-cage building.

Boilers, 470 boiler horse-power.

Chimney, 172 feet high; flue, 4 feet diameter.

Foundation, a bed of concrete 16 inches thick; on this 20-inch brick wall about 6 feet high, capped with a circular cast-iron shoe or base-plate. From this plate six sections of flanged cast pipe 4 feet 10 inches diameter are placed, lined with 4-inch fire-brick, capped again with a cast-iron plate on which stands the spigot end of the 4-foot inside diameter cast-

Photograph by Vernon Royle.

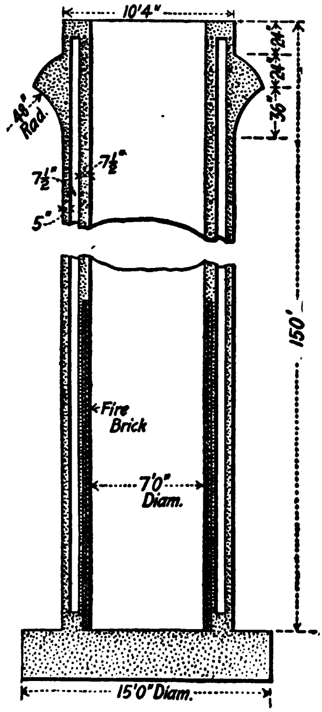
ILLUS. No. 42.

IRON FURNACES, STOCKHOLM, N. J.

Built about 1781, for forge using forced draught generated by water-power. Wheel and wood cylinder at the right of the picture.

iron water-pipe, which, with bell ends and spigot ends, makes the balance of height of chimney, excepting the upper section, which tops out in a moulding above which is a serrated edge. The chimney is anchored to the floor-beams by $\frac{3}{4}$-inch bolts.

In the building this chimney is surrounded by a double tile wall each 3 inches thick, 3-inch air-space between them, and greater air-space between tile and cast-iron chimney pipe. —*Engineering Record*, vol. xxxviii., p. 190.



ILLUS. No. 31.

PACIFIC COAST BORAX COMPANY, CONSTABLE HOOK, N. J.

MONOLITHIC FACTORY CHIMNEY.

Pacific Coast Borax Company, Constable Hook, N. J., 1898.

The entire mill is built of concrete and iron after E. L. Ransome's patent and by him, as is also the chimney.

Only the hottest zone of the chimney, bottom to 20 feet up, is protected by a fire-brick lining.

The reinforcement of this stack consists of $\frac{3}{4}$-inch rings two feet apart vertically and eight $\frac{3}{4}$-inch vertical bars in each wall of the chimney.

This chimney is built inside the factory, which protects it from wind strains up to a height of 70 feet, above which it rises 80 feet exposed to the elements.

The flue is 7 feet diameter by 150 feet high. Between the inner and outer shell are eight concrete and iron brackets, 6 inches wide, running the entire height of the chimney.—*Engineering Record*, vol. xxxviii., p. 189.

A light-house was erected in 1874 on the Isle of Jersey, of concrete, but built up of moulded blocks as ordinary masonry.

Its height is 135 feet on a rock 109 feet above the level of the sea.

Designed and erected by Sir J. Coode. It is recorded as a successful application of concrete.

Fr. Von Emperger, Proceedings *American Society of Civil Engineers*, 1894, says: "Two concrete structures which give the best proof of the elastic properties of this material (concrete) may be mentioned.

"One is a chimney 160 feet high, in Ireland, in one piece of concrete, which has stood the heaviest storms; and another example which is cited by Mr. A. Rella, are wine-tanks of a capacity of 80,000 gallons (of concrete only) in Agram, Hungary, which stood the last earthquake without cracking."

Sutcliff* says the first example in England of concrete chimneys was at Sutherland; the foundation was 12 feet square by 6 feet thick of concrete.

The chimney-base was 24 feet 9 inches high, 7 feet 6 inches square outside, and 4 feet square inside, lined with fire-brick.

Above the base was a moulding 21 inches high, and from this rose an octagonal shaft 30 feet high 15 inches thick at the bottom, and 9 inches at the top.

Concrete for base, 1 part Portland cement to 8 parts shingle and sand; for the shaft, 1 part Portland cement and 5 parts gravel and sand; rubble stones were also packed in the concrete as it was laid.

The finish was ¼-inch coat of cement (1 to 1) divided into ashlar.

Sutcliff speaks also of concrete chimneys being built elsewhere before this one.

Chemical Works Chimneys.—Chimneys used to carry off acid gases should be provided with exterior iron bands, and the interior have proper protection to the bricks, especially at the joints; the author would use only the best Portland cement, laid with close joints, for this class of work.

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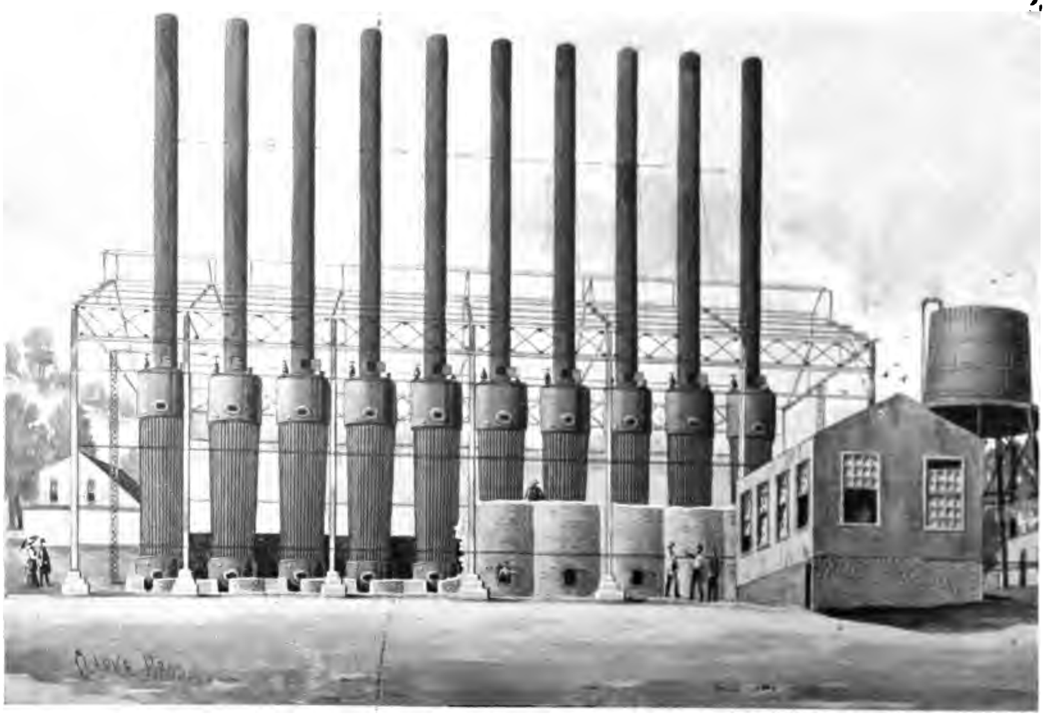
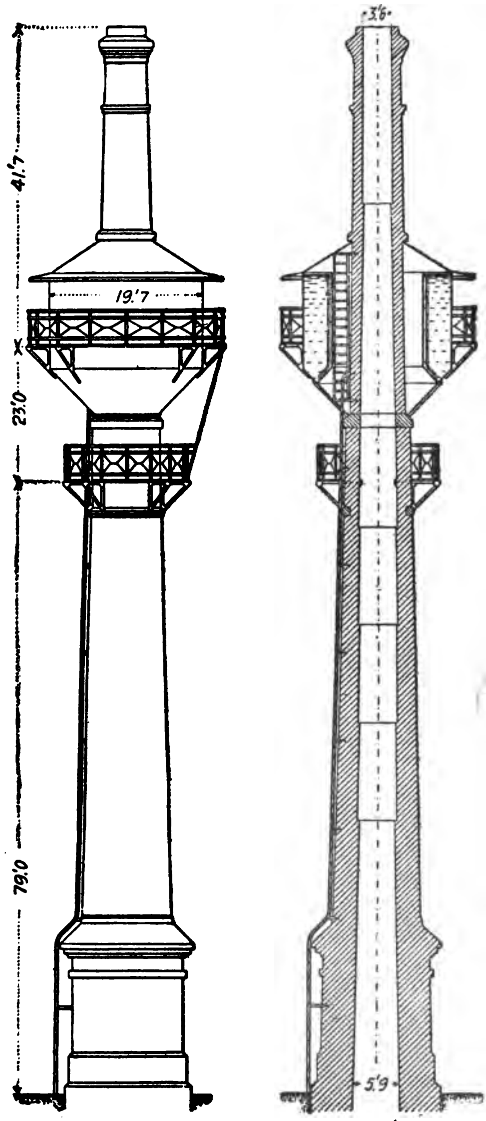
* "Concrete, Its Nature and Uses," published 1893.



ILLUS. No. 44.

CARNEGIE GAS COMPANY'S BAGDAD PLANT. CAHALL BOILERS.



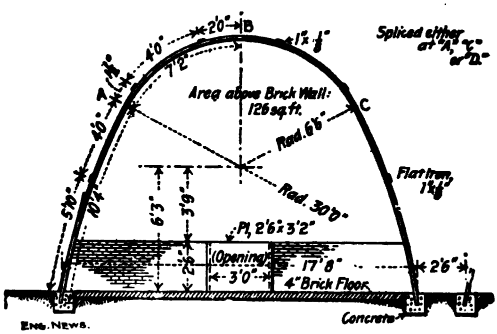
Engineering News.

ILLUS. No. 43.

A WATER TANK SUPPORTED UPON A BRICK CHIMNEY.

CONCRETE-STEEL DUST FLUE.

Engineering News describes a concrete-steel construction at the works of the Arkansas Valley Smelting Company, at Leadville, Col., where the dust flue conveying the smoke and gases from the roasting furnaces to the chimney is built of concrete, with an embedded metal skeleton. The flue is U-shaped in plan, with one leg of the U shorter than the other. The sulphurous gases from the roasting furnaces enter the short leg of the U from a tunnel below; pass around the loop, being somewhat cooled, and, depositing in the passage

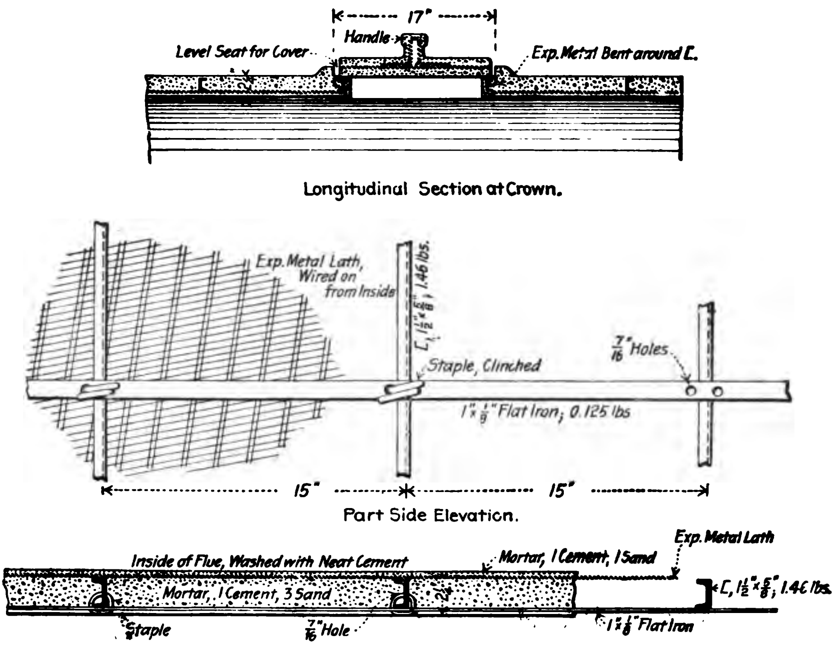


ILLUS. No. 46.

TRANSVERSE SECTION OF CONCRETE AND STEEL SKELETON DUST FLUE.

the valuable dust which it contains, finally pass out of the chimney into which the long leg of the U enters. Brick riffle-walls, placed at intervals across the bottom of the flue, aid in collecting the dust. The flue was designed by Mr. E. H. Messiter.

The construction of the flue is quite clearly shown by illustration No. 45. Illustration No. 46 gives a cross-section showing the main arch members, which are simply iron channel hoops bent to an arch and having their ends set in a concrete base wall. Between the base walls is a concrete floor resting directly on the ground. The channel iron arches are connected longitudinally by flat iron members connected to the



STRUCTURAL DETAILS OF CONCRETE AND STEEL SKELETON DUST FLUE.

ILLUS. No. 45.
CONCRETE AND STEEL DUST FLUE.

channels by clinched staples. Illustration No. 45 shows this connection, and also shows the arrangement of the lathing of expanded metal, which was fastened to the inside of the main flat and channel iron skeleton. The lathing and main skeleton were finally embedded in mortar composed of 1 part German Portland cement to 3 parts sand, to make a wall 2¼ inches thick, except at the crown, where a furnace slag concrete was employed. The inside of the wall was given a wash of neat cement paste. In one side of the wall a space was left for an iron plate door. The various other details of the construction are clearly shown by the drawings.

CHIMNEY AS TANK TOWER.

Professor O. Intze and F. A. Neumann, of Aachen, Germany, have patented such an arrangement. It consists of a brick chimney built as usual to where a tank is to rest, where a capstone is placed upon it; from there upward the outside size of the chimney is smaller, leaving a shoulder for tank brackets.

In an illustration in the *Engineering News*, vol. xxxix., p. 287, the total height of the brick chimney is 143 feet, the base for the tank being at 102 feet elevation.

Diameter of flue is 3 feet 6 inches at the top, and 5 feet 9 inches at the bottom. The steel tank has a capacity of 26,400 gallons, and space is left between it and the chimney for a ladder.

Several of these structures have been built of the capacity of the above, or less.

OTHER USES FOR CHIMNEYS.

The Coe Brass Company, formerly Wallace & Sons, at Ansonia, Conn., use an old square brick chimney as a clock tower.

The Richardson Manufacturing Company, at Newark, N. J., utilize their steel chimney to carry an exterior spiral staircase from an enclosed court to each floor of the factory building.

At the power-house of the Massachusetts General Hospital, Boston, Mass., scarcity of room and the smoke flues entering

"the chimney at a high level," allows of the interior of the lower part of the chimney being "used to contain a spiral stairway to connect the ground level and the floors."

COMPARATIVE COST.

Based upon figures given in the table, a chimney of 2,000 horse-power, if built of red brick, would cost about $8,500; of steel, self-supporting, full lined, about $8,300; of steel, self-supporting, half lined, about $7,800; of radial brick, about $6,800; of steel, self-supporting, unlined, about $5,820; of steel, guyed, about $4,000.

The following list is one which has been made up from actual costs, and may prove interesting in this connection:

Description.	Horse power, W. W. Christie's rating.	Cost, dollars. Total.	Cost, dollars. Per rated horse-power.	Remarks.
Radial brick, Circ.	1,645	6,000	3.64	American.
Radial brick, Circ.	13.484	40,000	3.00	Foreign.
Red brick, Circ.	4.040	16,000	4.00	
Red brick, Circ.	6,000	18,500	3.00	
Red brick, Rect.	450	2,192	4.87	
Red brick, Hex.	12,211	55,000	4.50	
Red brick, Circ.	4.859	10,000	2.06	Single shell, firebrick lining half height.
Red brick, Circ.	2,925	15,000	5.13	
Red brick, Circ.	5,772	40,000	6.93	
Red brick, Circ.	6.300	18,500	3.00	
Red brick, Circ.	6,000	25,000	4.25	
Red brick, Circ.	1,100	4,950	4.50	
Red brick, Rect.	517	1,900	3.80	
Steel, self-supporting.	2,400	10,000	4.15	Lined throughout.
Steel, self-supporting.	2,350	8,000	3.40	Half-lined, price without foundation.
Steel, self-supporting.	240	700	2.91	Unlined.
Steel, guyed.	240	400	1.66	Unlined.

An 80-inch centrifugal blower, 48-inch wheel, 4 × 3 inches double engine, blower and engine on beam platform, was erected in New England in 1899, connected with a 48-inch diameter chimney of No. 12 steel, 22 feet high, 10 feet of it above the roof, 1 inch thick cast base plate. The total cost for ap-

paratus, frame work, and mason work was $856. The boilers used in the plant, in connection with the blower, were horizontal tubular, one 80-inch diameter by 17½ feet; two 72-inch diameter by 17½ feet.

In the same year a self-supporting steel chimney, unlined, 3½ feet diameter by 105 feet high, was erected, with foundations and flue connections, at a cost of $1,013. The chimney was made of $\frac{3}{16}$, ¼, and ⅜ inch steel. The blower outfit works satisfactorily in the part having two boilers with a total of 75 square feet of grate. The chimney gives a very satisfactory draught for 93 square feet of grate surface, and if it had been made 48 inches diameter, as in the blower outfit mentioned, and been guyed with wire rope, with a light foundation, $800 would easily have met the expense.

A CHIMNEY ON LOOSE SOIL.

An interesting description is given in *Dingler's Polytechnisches Journal*, vol. cclxvii., p. 194, of a chimney built on loose soil; thus rendering a light structure necessary, says the London *Builder*. From the foundations four upright, and somewhat tapering, lattice-girders were carried up, and connected together by cross bracing. On the inner edge of the frame thus formed the chimney proper was built of tiles, about five inches in thickness, and having lap joints. Angle-iron bands were introduced at intervals to bind the whole firmly together. The total height of the chimney is 140 feet, and the inside diameter 8 feet 6 inches. The total weight is 543 tons, which gives a pressure of 17 pounds per square inch on the foundation, 2.2 tons per square foot. This would be about equal to half the weight and pressure per square inch of an ordinary chimney. The whole chimney was erected in thirty-nine days, the iron-work occupying thirty-one days of the time. The cost is set down at 19,200 francs,* and it is estimated that a brick chimney of the same height and size would have cost 14,300 francs.†

* $3,698. † $2,752.

HIGH CHIMNEYS ARE NOT NECESSARY.

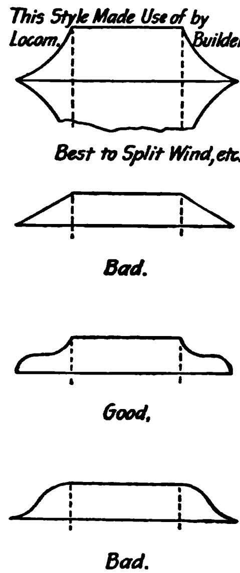
In the language of Professor Wood they are "a monument to the folly of the builders."

While multiple chimneys do not look as imposing as one stately structure, yet better results are often obtained by their use.

A notable example of chimneys in multiple is at the Spreckles Sugar Refinery, Philadelphia, Pa., where five chimneys are used for one plant of 7,500 horse-power of boilers, costing less than one chimney for the combined plant.

The new plant of the Carnegie Steel Company, Bagdad, Pa., is a still more striking example, as shown by Illus. No. 44.

The author has changed one plant from one chimney for two boilers to three chimneys for three boilers, with very beneficial results.



Chimney Top Designs.

STRAIGHTENING A CHIMNEY.

The Standard Concrete Manufacturing Company, Earnest, Pa., have a brick chimney 122 feet high, 11 feet square at the base, with tapering walls, weighing 400 tons; walls 36 inches thick.

The top leaned 45 inches from a vertical line. To sink the side $4\frac{1}{2}$ inches, $10\frac{1}{2}$ inches of brickwork were removed at the foundation from three sides, and square blocks of wood put in their places—brick piers being built 6 inches high so as to leave the $4\frac{1}{2}$ inch space.

The wood was then set on fire and made to burn evenly. As the top gradually swung over, small fissures which appeared on the bottom were filled with steel wedges, to maintain solidity of the walls.

The work consumed one day, the burning of the blocks one hour.—*Engineering News*, vol. xxxvi., p. 160.

CHIMNEY ACCIDENTS.

"The lecture of H. Lütgen, 1884, that in a manner similar to other chimney accidents (see for instance Cordeir's report concerning capsizings in France) all chimneys blown down have broken off either slightly above or below the centre.

"For the granting of an equal steady wind-pressure the upper parts become weak in proportion to the lower part," and "it is well known that in Germany the storm of the year 1876 threw down only such chimneys as were in use among a large number of the same kind and sizes of chimneys" caused by the weakness accompanying the heat from the gases.

A brick chimney with a flue about 5 feet inside diameter by about 160 feet high, being built in a New Jersey city, in 1890, was nearly completed, when struck by an extended severe northeast storm, and though the top was covered, yet the mortar being green, a major portion of the structure came down, so much that an entire rebuilding of the shaft was necessary.

A 200 feet high octagon chimney, with a flue 8 feet in diameter (of the inscribed circle), which had been just completed for the Hoepfner Refining Company, Hamilton, Ont., Canada, collapsed early on the morning of April 18, 1900, necessitating the rebuilding of everything above the foundation.

The apparent cause of this disaster was building the chimney when the lime mortar froze as it was laid, and the consequent expansion was built upon day after day; when the spring sun thawed out the frost the masonry settled and the collapse was the result.

TEARING DOWN OR RAZING A CHIMNEY.

The *Engineering News*, May 17, 1894, gives some details in relation to the successful tearing down of a square brick chimney, 75 feet high, by use of four dynamite cartridges set off at once.

A brick chimney at the Tees Iron Works, Middlesbrough, England, was taken down by using a tight vertical box the cross-section of which was the size of a brick, and dropping the bricks in at the top; when a number had reached the bottom they were removed; the air-cushion provided by the closed box prevented breakage to any considerable extent.—*Engineering*, London, vol. xii., p. 189.

A brick chimney, 160 feet high and 8½ feet square at the

base and 4½ feet diameter at the top, was overthrown lately in St. Louis by the use of hydraulic jacks. The chimney belonged to the old Belcher Sugar Refinery, and contained about 200,000 bricks. The chimney was first undermined on one side, and three 10-ton hydraulic jacks were placed in position under the side. A hawser was then fastened about the chimney, 60 feet from the ground, and ropes led from this hawser to crabs placed at a distance of about 100 feet from the chimney. With eight men at each crab and men at the hydraulic jacks, the chimney was slightly lifted and pulled at the same time; the men at the jacks left their posts at the first warning crack, but those at the crabs continued their work until the chimney fell. The top of the chimney toppled over first and the base followed. The work was performed by P. W. Hassatt, contractor.—*Engineering News*, 1899.

STRAIGHTENING A CHIMNEY.

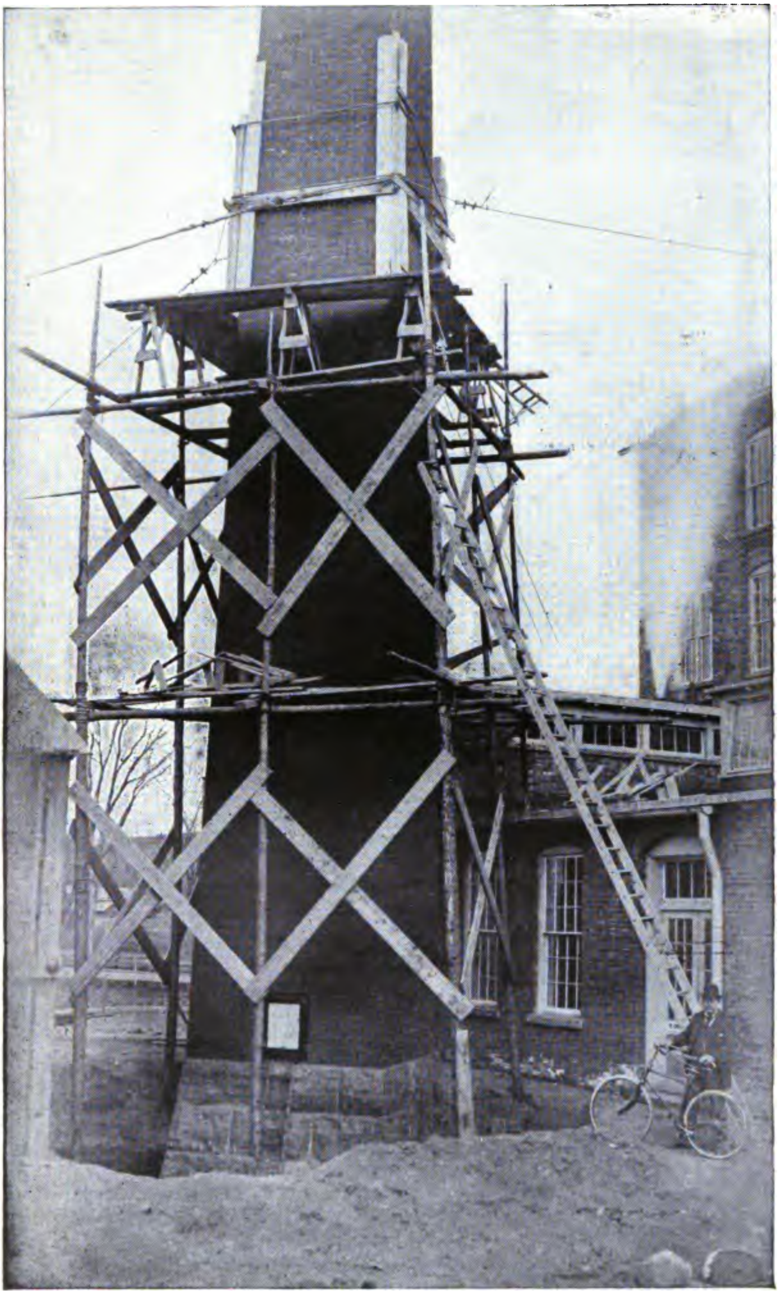
Square brick chimney, 100 feet high, leaning 28 inches, at factory of Ormsby Textile Company, Waterford, N. Y., erected in 1893, located one-third of a mile from the west bank of the Hudson River on north side of outlet of Mohawk River. The underlying rock is shale, irregularly covered by earth.

Chimney is 5 feet 4 inches square at the top, and 9 feet 6 inches square at the bottom, and has a flue 3 feet square; its foundation is 14 feet deep—4 feet by 14 feet square being concrete, and heavy stone-work 10 feet by 14 feet square at bottom, tapering to 9 feet 6 inches at top. Foundation weighs 149 tons, making with chimney 355 tons on 196 square feet of earth, or about 1.8 tons per square foot.—"Transactions of the American Society of Mechanical Engineers," paper dcxi.

This chimney settled in all about 0.598 of a foot. The manner in which it was straightened is described by Mr. J. C. Platt in part as follows:

"The work of straightening the chimney commenced on March 19, 1894. A scaffold was erected, and eight oak timbers, 6 inches by 10 inches by 10 feet, were placed at the corners at the height of 42 feet above the stonework, and 4½ feet below the centre of gravity of the brickwork; the object of the oak timbers being to spread the bearing of the wire ropes over as large a section as practicable.

"Wire ropes were passed around the timbers, and another



ILLUS. No. 47.

ORMSBY TEXTILE COMPANY, WATERFORD, N Y.

wire rope $2\frac{1}{2}$ inches in diameter with eye in each end, was fastened to the first-mentioned ropes at its upper eye.

"The lower eye was connected with a system of pulleys secured to the dock at the river edge at a distance of 78 feet, and directly opposite the direction in which the chimney leaned, the pulleys being made up of three sets of double and single blocks connected together in series, having three points of fastening to the dock, and having eleven pulleys in a system.

"Cables were also put out from the chimney on each side at right angles to the main cable, and having turn-buckles to tighten them; also a guard cable in the rear.

"The earth was then excavated on the high side of the foundation nearly one-half way around the bottom of the foundation (to a depth of 13 feet), and the main cable put under strain with the pulleys.

"In the course of three weeks the chimney was brought back about 4 inches.

"Then with a post-hole digger, 8 inches in diameter, eleven holes were sunk vertically in the bottom of the trench around the foundation, principally at the highest point, to a depth of 5 feet 6 inches to 6 feet. At this time the water in the river stood up to within $1\frac{1}{2}$ feet of the bottom of the foundation; the ground being soft to a depth of 4 feet, it then became very hard, showing that the strata supporting the chimney had been reached.

"No movement or flow of the soil was discovered until the eighth hole was sunk $4\frac{1}{2}$ feet and the tool withdrawn for clearance, when it could only be reinserted readily about 3 feet and headway made very slowly.

"From this removal of the earth there resulted within a few hours a righting of the chimney of 5 inches, increasing to 8 inches by the next morning.

"The slack of the pulling-rope was taken up as fast as the chimney moved, and the rope was kept under strain.

"By tightening up the pulley-rope two or three times a day, in a week the chimney was brought back to $8\frac{3}{4}$ inches.

"In similar manner, the post-hole diggers being reduced to 6 inches diameter, about one-fifth as much more material was

removed, immediately followed by righting the chimney to 4 inches, and from that point, after filling the holes with fine broken stone and gravel thoroughly rammed, by continued daily strain on the main cable the chimney was brought back to plumb at the rate of a quarter of an inch per day.

"The turn-buckles in the side cables were occasionally used to control any tendency toward lateral inclination.

"The work has been accomplished without injury to the structure."

Chimneys have been straightened at Louisville, Ky., in a similar manner.

CHIMNEYS FOR FORCED DRAFT.

Chimneys for forced or induced draft should be made of sufficient diameter to carry off the products of combustion; and the writer recommends the top of such chimneys to be at least 15 feet above the top of the boiler-house roof or the roofs of adjoining structures.

If the greatest diameter of chimney flue, corresponding to the given horse-power or boiler plant, be looked up in the authors' table No. 8 for chimney sizes, it will coincide very closely with present practice, and give abundance of room, so as not to necessitate too high a velocity for the gases.

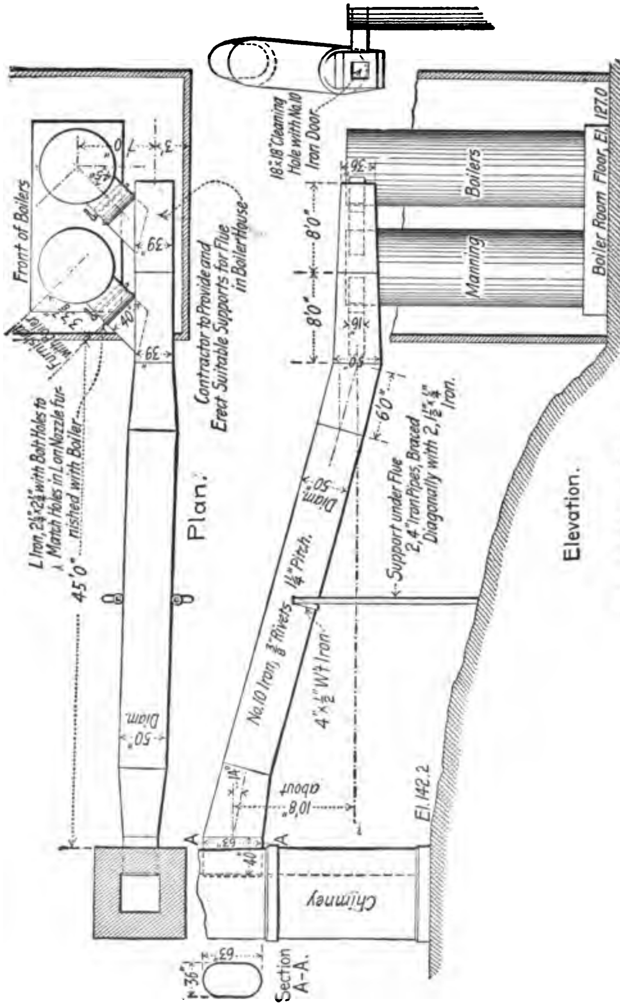
The above is applicable to either brick or steel chimneys.

By the use of the fan, high and expensive chimneys are done away with, and the capacity is not as limited as the ordinary chimney, and while the draft of the ordinary chimney is affected by the weather and climatic conditions, forced or induced draft can be regulated so as to be nearly constant in its effects, and there is less waste of heat of the flue gases.

The cheap grades of fuel can be used, in fact anything that will burn at all can be made use of, and money possibly saved, though the interest of the investment must be met, and the running expenses of the draft-producing appliance is never ending.

Provided mechanical draft is an easily applied remedy, unless the flue in the chimney is large enough of area, the results obtained will not meet one's expectations as well as a properly designed chimney; it may be said, however, that

ILLUS. No. 48.
ORMSBY TEXTILE COMPANY, WATERFORD, N. Y.



Flue for Vertical Boilers.
ILLUS. No. 49.

mechanical draft is a necessity in the burning of dust and rice coal and other cheap fine fuel.

FLUES.

In conveying the gases from the boiler furnace to the chimney a flue must be used fitted with an easily swinging damper close to boiler connection, and be made as air tight as possible all of the way to chimney flue.

Having seen that there is less friction in a round than square chimney to the flue gases, we should make the flue round whenever possible, and it is more easily built, while the square flue needs flanged corners or special angle-iron corners.

Round flues for more than one boiler are made tapering from a small size at first boiler to the largest size at chimney.

The area of the flue should be at all sections as large or larger than the total area of tubes emptying in it at that section.

When more than one flue is to connect with a chimney from opposite sides, a partition or deflector is provided so as to separate the two currents of gases, and deflect them upward.

Sometimes one opening is made at least three or four times its diameter above the other flue inlet, without a separator.

Overhead flue connections are of steel sheets, those under ground are sometimes of steel, but often of fire-brick laid in fire-clay and covered with red brick.

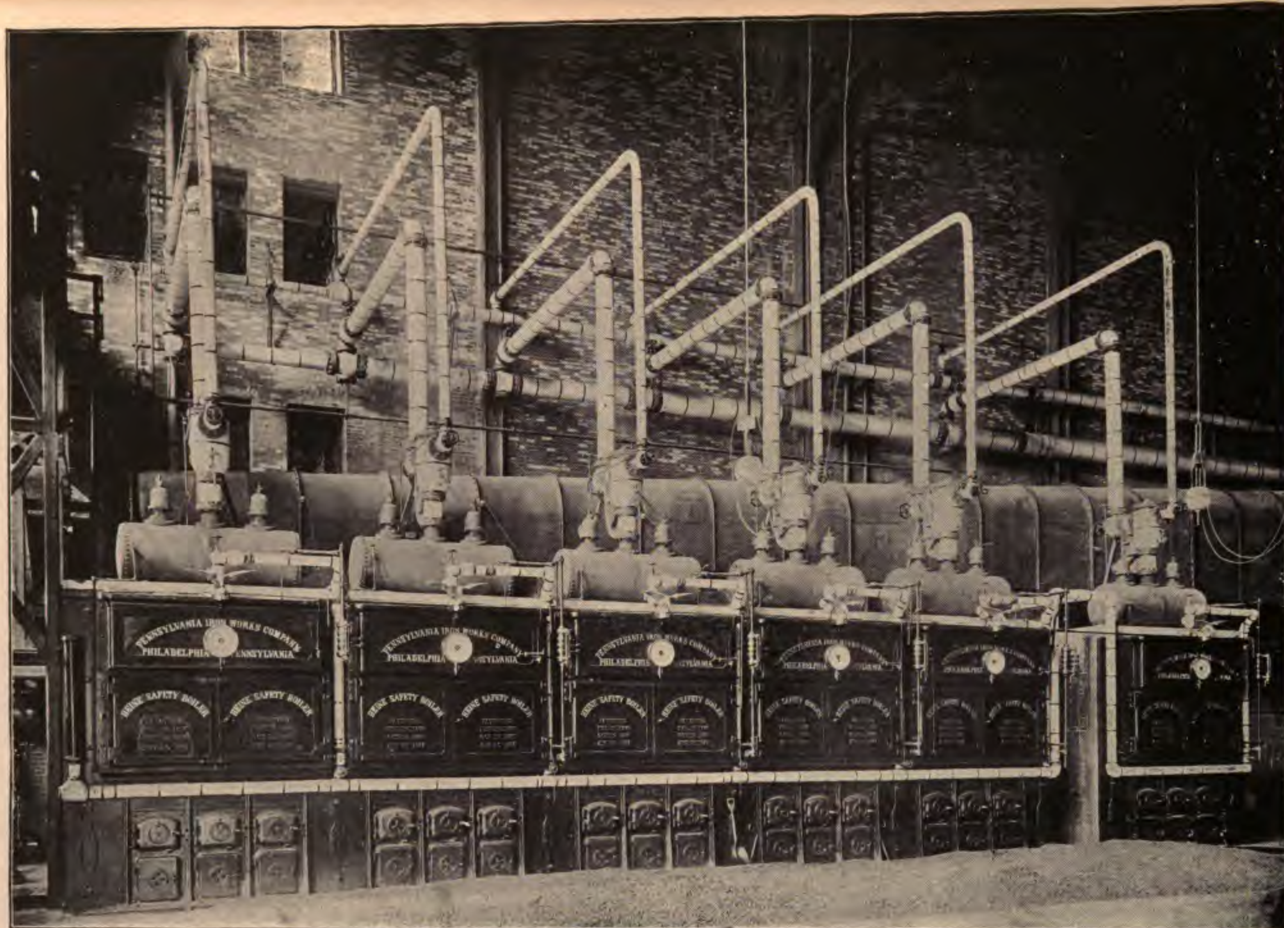
Exposed flues should be protected with hair felt, asbestos board, or some other heat retainer, that all the heat from the gases may be available in the chimney proper for draft.

The effect of changing the length of the flue leading into a chimney 60 feet high and 2 feet 9 inches square is as follows:

TABLE No. 26.

DRAFT POWER—VARYING FLUE LENGTHS.

Length of flue in feet.	Horse power.	Length of flue in feet.	Horse-power.
50	107.6	800	56.1
100	100.0	1,000	51.4
200	85.3	1.500	43.3
400	70.8	2.000	38.2
600	62.5	3.000	31.7



"Helios."

ILLUS. No 50.

FLUE ARRANGEMENT 1,500 HORSE-POWER PLANT OF HEINE BOILERS, PART OF 4,500 HORSE-POWER PLANTS OF BROADWAY AND SEVENTH AVENUE CABLE RAILWAY COMPANY, NEW YORK.

The following table may also be useful.

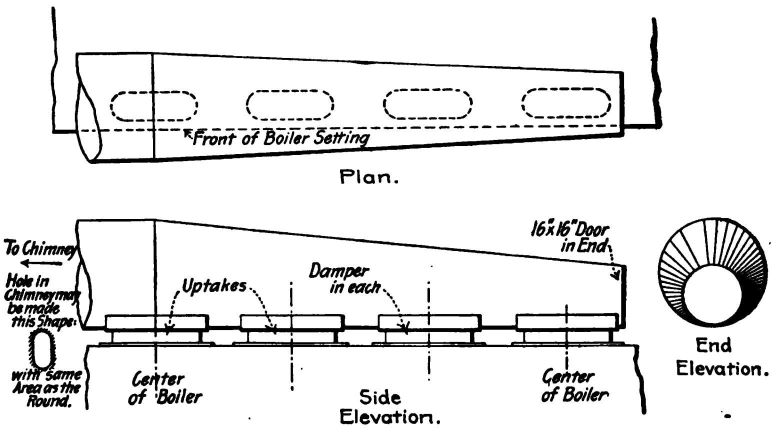
TABLE No. 27.

REDUCTION OF CHIMNEY DRAFT BY LONG FLUES.

Total length of flues in feet....	50	100	200	400	600	800	1,000	2,000
Chimney draft in per cent.....	100	93	79	66	58	52	48	35

In the above the total length from grate to base of chimney must be considered.

When several boilers are connected with one flue, increase size as before noticed.



Flue for Horizontal Return Tubular Boiler.

ILLUS. No. 51.

INFLUENCES OF TURNS AND ELBOWS UPON FLUIDS IN MOTION.*

Let us consider first the influence of abrupt changes of direction and later those of continuous changes, that is to say, of curved pipes.

M. d'Aubuisson has made several experiments on the influence of abrupt changes of direction. In his "Traité d'Hydraulique," p. 513, appears the following:

* Translated from M. E. Péclet's Traité de la Chaleur, by F. R. Low.

"Elbows in conduits, when they are abrupt, augment considerably the resistance to movement. In my numerous experiments on conduits with elbows, seven 45-degree turns reduce the flow one-quarter.

"In these experiments I noticed that the resistance increases, as in water pipes, sensibly as the square of the velocity and nearly as the square of the sines of the angles. Beyond a certain number, however, the resistance even diminished; thus fifteen angles reduced the outflow a little less than seven of the same size. This phenomenon and other circumstances have rendered futile the attempts that I have made to establish, even approximately, the resistance of the elbows. In

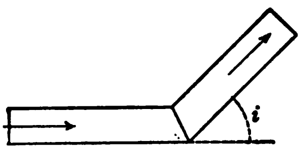


FIG. 1.

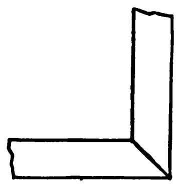


FIG. 2.

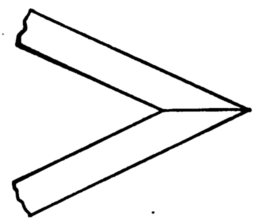


FIG. 3.

practice a bad effect may be avoided by rounding well those curves which it is necessary to make."

According to the experiments made by Dubuat' on water pipes, the resistance of an abrupt change is sensibly represented by $p \sin^2 i$, p being the head corresponding to the velocity of flow, and i the angle which the second pipe makes with the prolongation of the first. For gas which flows under a light pressure, and which in consequence undergoes only insensible variations of density, it was probable that the resistance of the elbows would follow the same law, but it was important to verify this, the more so that in the experiments of Dubuat' the angles i were always between 36° and 56°. As to the singular result found by d'Aubuisson, that from a certain limit the flow increased with the number of angles, it can be explained only by admitting that the joints were not entirely tight.

It results from numerous experiments which I have made on abrupt changes of direction that when the angle i, Fig. 1, of the second pipe with the prolongation of the first is between 20° and 90°, the loss of head is given by the formula:

$$P_1 - p_1 = p \sin^2 i$$

as for pipes carrying water.

P_1 is the head before the elbow,
p_1 is the head after the elbow,
p the head corresponding to the velocity.

For angles between zero and 20 degrees, it will be necessary to consider the elbow as a curved pipe and employ the formula which will be given later.

If the angle was a right angle, Fig. 2, the loss of head would be p, and for n changes at a right angle it would be $n\,p$.

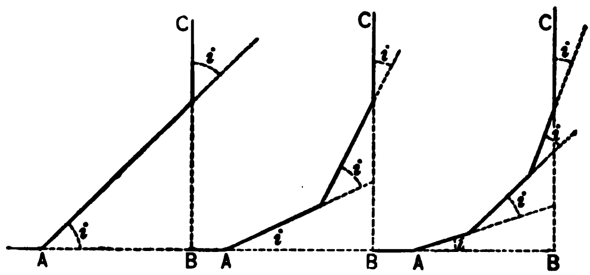


Fig. 4.

For an angle greater than a right angle, as in Fig. 3, the loss of head is uncertain. From some experiments it appears that for the angles made by the second pipe with the prolongation of the first comprised between 110 and 160 degrees, the loss of head would vary from $2p$ to $2.28p$; but these experiments were not sufficiently regular and consistent to justify a great deal of confidence in them. This case, however, rarely presents itself in practice.

The total resistance of the abrupt changes in a circuit being equal to the sum of the resistance of each one of them, if it is imagined that the right angle formed by the two pipes AB and BC, Fig. 4, were replaced by three, four, or five pipes,

disposed symmetrically, the angles i being equal, their sum would be equal to 90 degrees, and designating by n the number of angles i, the total resistance would be

$$n \sin^2\left(\frac{90^\circ}{n}\right).$$

If n be supposed successively equal to

	1	2	3	4
the value of i will be	90°	45°	30°	22° 30′
of which the sines are	1	0.707	0.50	0.382
and the losses of head become	1	1	0.75	0.58

Thus a single pipe cutting a right angle does not diminish the resistance appreciably, and three intermediate pipes do not reduce it quite to one-half.

CURVED PIPES.

The earliest experiment on the flow of fluids in curved pipes was made by Bossut. A pipe of 16.24 metres in length and 27 millimetres in diameter discharged under a head of .325 metre a volume of .0028 cubic metre of water in a minute when it was in a straight line, and .02048 when it was turned upon itself so as to form six well-rounded elbows. It seemed, according to this experiment, that well-rounded elbows had not much influence on the flow, but as the pipe was quite long, the loss of head was in part confused with that which came from friction.

Dubuat made a considerable number of experiments to determine the resistance of curved elbows in water-pipes, and this engineer has been led to a singular explanation of the resistance in question. He maintains that when the water issues from a rectilinear canal, AB, Fig. 5, and penetrates into a curved canal, BCD, the elementary veins do not follow the curvature of the pipe, but are reflected on its surface, and that the loss of head produced by the curved pipe is due to these reflections of the lines of water. According to his experiments the loss of head would be expressed by

$$0.0123\, v^2 (s^2 + s'^2 + s''^2 \,.\,.); \text{ or } p\, 0.24\, (s^2 + s'^2 + s''^2)$$

$s\, s'\, s''$ being the sines of the angles of reflection.

Where the curvature of the pipe is circular, all the angles of reflection are equal, and the above expression becomes

$$p\, n\, sin^2\, i.$$

The angles of reflection are those which correspond to the central vein. D'Aubuisson accepts completely this explanation of the resistance of curved pipes, and the formula of Dubuat ("Traité d'Hydraulique," p. 182). Notwithstanding the authority of these two engineers, such an explanation appears to me to be inadmissible. First, the fluids, liquid or gaseous, do not reflect against the surfaces which they encounter, and in the second place, if this reflection did occur, it would not be the same for all the elementary veins which penetrate into the curvilinear pipe, and for which I think the values of i and n would be different.

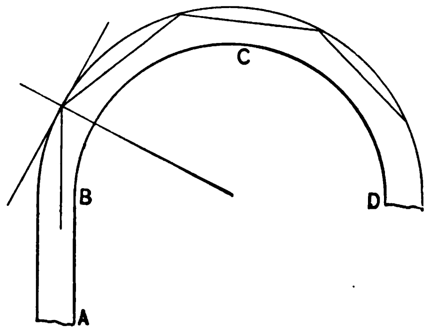


FIG. 5.

I made a great number of experiments to determine the losses of head from rounded elbows, Fig. 6, from which it appears that we shall not be far from truth in considering that the resistance of a curved pipe of constant section is sensibly equal to

$$P_1 - p_1 = \frac{i}{180} p$$

i being the number of degrees of the arc, p the head corresponding to the velocity of flow, P_1 and p_1 the head before and after the curvature. Thus for a semicircle which will bring

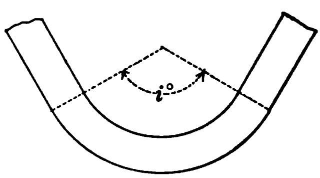


FIG. 6.

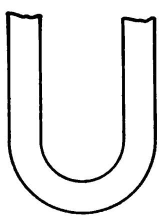


FIG. 7.

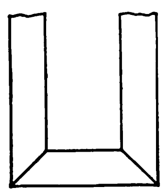


FIG. 8.

the pipe into a position parallel to the initial direction, Fig. 7, we have $i = 180$ degrees, and the loss of head would be p, one-half only of that which would take place if the pipe had taken that direction by two abrupt and successive right-angled changes, Fig. 8. If there were n continuous changes of direction the loss of head would be

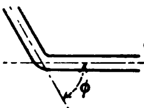
$$P_1 - p_1 = \frac{i}{180} p$$

—*Power*, February, 1900.

Weisbach, from experiments with 1¼-inch pipe (water) found the loss of head to be $h_e = G_e \frac{v^2}{2g}$,

$$G_e = 0.9457 \sin^2 \frac{\phi}{2} + 2.047 \sin^4 \frac{\phi}{2}$$

Elbows.—



$\phi =$	20°	40°	60°	80°	90°	100°	110°	120°	130°	140°
$G_e =$	0.046	0.139	0.364	0.74	0.984	1.26	1.556	1.861	2.158	2.434

hence at a 90-degree elbow the whole head due to the velocity is very nearly lost.

Bends.—For curved bends, ○ cross-section, $h_b = G_b \frac{v^2}{2g}$,

$$G_b = 0.131 + 1.847 \left(\frac{d}{2r}\right)^2$$

where d = diameter of pipe, r = radius of curvature of bend.

For ☐ cross-sections

$$G_b = 0.124 + 3.104 \left(\frac{s}{2r}\right)^{\frac{7}{2}}$$

where s is the length of side of section parallel to the radius of curvature, r.

$\frac{d}{2r} =$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	○ section.
$G_b =$	0.131	.138	.158	.206	.294	.440	.661	.977	1.408	1.978	

$\frac{s}{2r} =$	0.1	0.2	0.3	0.4	0.5	0.6	.07	0.8	0.9	1.0	☐ section.
$G_b =$		0.124	.135	.180	.250	.398	.643	1.015	1.546	3.228	

CHAPTER IX

HOUSE CHIMNEYS

HOUSE-HEATING

SCHUMAN * gives these formulæ for house-heating calculations.

Let A = sectional area of flue in square feet.
V = volume of smoke delivered in cubic feet per second; usually 600 is allowed for V.
K = pounds of coal consumed per hour.
H = height of chimney in feet.
v = velocity of smoke in feet per second.
t = external temperature, average 50°.
t_1 = internal temperature, average 550°.

$$(58)\quad v = 0.08\sqrt{(t_1 - t)H},$$

$$(59)\quad A = \frac{12.5\,V}{\sqrt{(t_1 - t)H}},$$

$$(60)\quad V = Av = A\,0.08\sqrt{(t_1 - t)H},$$

$$(61)\quad H = \frac{156}{t_1 - t}\left(\frac{V}{A}\right)^2,$$

allowing 600 for V, we have

$$(62)\quad A = 0.128\frac{K}{\sqrt{H}},$$

$$(63)\quad H = 0.01638\left(\frac{K}{A}\right)^2.$$

The following table is adapted from the Blackmore Heating and Ventilation Company for hot-air furnaces.

* Manual of Heating and Ventilation, p. 69.

TABLE No. 28.

SIZE OF CHIMNEY FLUE.

Diameter of grate. Inches.	Area of grate. Square inches.	FLUE. INCHES.	
		Round.	Rectangular.
16	201	9	8 × 8
18	254	9	8 × 8
20	314	11	8 × 12
22	380	11	8 × 12
24	452	14	12 × 12
26	530	14	12 × 12
28	615	16	12 × 16
30	706	16	12 × 16
32	804	16	12 × 16

H. J. Barron, New York City, gives the following:

Chimney for a small dwelling............ .... 8 × 8 inch, rectangular flue.
Chimney for a large dwelling .... 8 × 12 inch, rectangular flue.
Chimney for a five-story flat, 25 × 80 feet .... 12 × 12 inch, rectangular flue.
Chimney for a six-story flat, 36 × 80 feet...... 16 × 16 inch, rectangular flue.
Chimney for a church, 400,000 cubic feet..... 20 × 20 inch, rectangular flue.
Chimney for a school, 100 × 100 feet......... 20 × 20 inch, rectangular flue.
Chimney for an office building, 100 × 100 feet. 30 × 30 inch, rectangular flue.

The Herendeen Manufacturing Company, Geneva, N. Y., give:

For grates 16 inch diameter to 22 inch diameter........ a flue 8 × 8 inches.
For grates 24 inch diameter to 26 × 34 inch rectangular a flue 8 × 12 inches.
For grates 28 × 36 to 36 × 42 inches rectangular....... a flue 12 × 12 inches.
For grates 36 × 56 inches rectangular.................. a flue 12 × 16 inches.
For grates 44 × 56½ to 44 × 70½ inches rectangular..... a flue 20 × 20 inches.

For chimneys in residences or other buildings where stoves or hot-air heaters are used, or where a low rate of combustion is desired, the writer proposes this formula, which is a very satisfactory one.

$$(64) \quad K = 2A\sqrt{H},$$

where K = grate area in square feet,
A = flue area in square feet,
H = height of chimney or flue in feet.

Giving H the value 49, which is somewhere near the height of house chimneys, the following table has been calculated:

TABLE No. 29.

GRATE.		CHIMNEY.	
Diameter, feet.	Area K, square feet.	Area A, square feet.	Diameter, inches.
1.6	2.0	0.571	10.3
1.80	2.5	0.714	11.4
1.95	3.0	0.858	12.6
2.10	3.5	1 000	13.5
2.25	4.0	1.142	14.5
2.4	4.5	1.285	15.5
2.52	5.0	1.429	16.2
2.64	5.5	1.571	17.0
2.76	6.0	1.714	17.8
2.98	7.0	2.000	19.2
3.19	8.0	2.285	20.5
3.38	9.0	2.571	21.7
3.56	10.0	2.858	22.9
3.74	11.0	3.142	24.0
3.90	12.0	3.429	25 1

The J. L. Mott Iron Works, from data gained during a long experience and close study of the subject, recommend the following table and its accompanying chimney proportions as absolutely safe.

TABLE No. 30.

Size of house in cubic feet.	RADIATING SURFACE.		Size of chimney. Inside measure. Inches.
	Square feet of direct hot water.	Square feet of steam.	
12,000	350 to 450	250 to 300	8 × 8
15,000	450 to 550	300 to 350	8 × 12
18,000	550 to 650	350 to 450	8 × 12
24,000	850 to 1,000	500 to 600	8 × 12
30,000	1,000 to 1,200	600 to 700	12 × 12
36,000	1,200 to 1.600	700 to 900	12 × 12
42,000	1,600 to 2,000	900 to 1,200	12 × 12
60,000	2,000 to 3,000	1,200 to 1,600	12 × 16
80,000	2,500 to 4,000	1,500 to 2,000	12 × 16
100,000	3,000 to 4,500	1,800 to 2,300	16 × 16
150,000	3,500 to 5,000	2,000 to 2,600	16 × 16
200,000	4,000 to 6,000	3,000 to 4,000	16 × 20
300,000	5,000 to 8,000	4,000 to 5,000	16 × 20
400,000	8,000 to 12,000	5,000 to 6,500	20 × 20
500,000	10,000 to 14,000	6,000 to 8,000	20 × 24
700,000	13,000 to 18,000	7,500 to 9,500	24 × 24

No illustrations of house chimneys are given in this work, for the reason that, having determined the flue proportions by engineering methods, all that remains is to provide a neat exterior, which is purely architectural in its demands; but the designer should bear in mind two things: first, to be plain in the treatment of the chimney top; second, build it high enough above roofs and surrounding objects, that there will be no down drafts or wind eddies to contend with.

As in mill construction so in house construction there is no detail which plays so important a part in the comfort of the occupant as the chimney which gives the draft to the heating apparatus.

It is an appurtenance which receives but little consideration in many cases, the architect or engineer being very liable to copy some one else's proportions in preference to working out the problem again, having determined the general flue dimensions by the general rules.

House chimneys should be made as straight as possible, and if slight bends occur they should be of the same cross-sectional area as the straight part, and be made round in shape, as this shape gives much less frictional resistance than a square flue. An inside flue is much better from any engineering standpoint than one outside of the building exposed to the weather.

Ample area is especially desirable in a house chimney, that the flue may take care of the smoke of the oft kindled fire, and area must be sufficient to counteract minimum draft.

House chimneys are usually built of brick, 4 inches thick around the flue for small chimneys, and 8 to 12 inches for very large chimneys.

For house-heating a flue 8×12 or 8×8 is the smallest that should be built, not because that area is necessary, but to overcome roughness of construction and of cleaning. For large houses use not less than 12×16, and for steam plants use the writer's formulas and tables for anthracite coal, and elsewhere in this volume.

All other conditions being equal, the coal capacity of a chimney varies as the square root of the height, the difference of temperature* within and without the flue, and the flue area.

* Absolute temperature.

The straighter and more true the flue the more powerful the draft will be, but there are cases where even the best constructed and designed chimneys may and do smoke.

Fred. Hodgson says: "Some causes of chimneys smoking are well known and avoidable, the trouble arising perhaps from positive ill construction, having a narrow part and angle bend, or a downward portion in their conduit, which their normal draft is not sufficient to overcome.

"Others smoke because they form the shortest channel by which the air can enter the house to supply the draft to a higher chimney.

"When there are two chimneys in one room, or in rooms adjacent to each other, and the doors and windows are closed in all other rooms, the shorter will have its draft inwardly to supply the other with a current."

Sometimes the best constructed and most carefully designed chimney, with regard to the building in which it is situated, will smoke in consequence of its exit being in the immediate neighborhood of walls, hills, or trees whose situation is such as to create at times strong eddies and cross-currents.

In most cases, however, the addition of a few feet or so to the height of a chimney-shaft, supposing it to be already above the ridge of the house which it ventilates, will prove more useful than any addition of those curiously contorted and usually non-pneumatic contrivances that are so often planted on the top of a smoking chimney to cure it of its "cussedness."

Apart from the questions of normal draft and of internal regularity of construction, is the effect of wind on draft of chimneys. This varies very much with the locality of the house. The action of the wind, although, of course, always determined by physical laws, is so subtle and so delicately affected by slight causes, that there are many cases in which it is impossible to foretell it.

What is more common than to have a chimney that has been built according to the rules relating to chimneys, and which answers its purpose perfectly well, except when the wind is in one particular point of the compass.

And why does it smoke?

To be able to reply to this question is to be able to cure the defect; but how often is the difficulty regarded as insuperable?

The celebrated philosopher Count Rumford paid great attention to the subject of smoky chimneys.

He says: "Those who will take the trouble to consider the motion and properties of elastic fluids, of air, smoke, and vapor, and to examine the laws of their motions, and the necessary consequences of their being rarefied by heat, will perceive that it would be as much a miracle if smoke should not rise in a chimney—all hinderances to its ascent being removed—as that water should refuse to run in a siphon or to descend in a river.

"The whole mystery, therefore, of curing smoky chimneys is comprised in this simple direction: find out and remove those local hinderances which forcibly prevent the smoke from following its natural tendency to go up the chimney, or rather, to speak more accurately, which prevent it being forced up by the pressure of the heavier air in the room."

It is on record that Count Rumford prescribed for and cured more than 500 chimneys that had been given up as incurable, and his services were in constant demand whenever he was disposed to render them.

In Southern Italy, the land of "Master Builders," all chimneys are built over with some sort of a roof, either arched or run up to an acute angle, and so no architect ever thinks for a moment of leaving a vertical flue open at the top to receive the tremendous downpour of rain, which occasionally occurs in that sunny land.

The covering of the chimney, whatever it may be, has a number of apertures in its sides for the escape of smoke, and these openings are so constructed that when the wind strikes against them it receives an upward tendency, as the bottom or lower portions of the aperture slant upward in the same manner as a louvre board.

By this method of construction two objects are attained, the slant carries the wind upward and thereby increases the draft by suction, and it prevents the water from finding its way down the flue.

A number of mill and house chimneys have their draft improved, and that to a considerable degree, by placing a blue-stone slab or iron-plate cover above the top with abundant side openings.

Another common cause for smoky chimneys that defies remedy, is the rubber weather-strips on doors, and other draft preventives, which keep all air from entering a room.

Such inlets must be allowed to exist, or special air inlets provided if we wish our chimneys to draw; again, high trees break up the wind currents as they come near a chimney and thus interfere with the draft.

BUILDING A CHIMNEY.

Brick chimneys seldom receive the care in construction that so important a structure should have.

The best and hardest bricks are usually put in the outer walls of a house, and the soft bricks, or "bats," relegated to the chimney.

This is folly, as will be appreciated by any one with a knowledge of the subject.

Good brick may be used at the top, but it is not there that there is danger of the fire eating through, but within the building where the soft brick have been used.

Tile flue-lining is rapidly coming into use and rightfully, as it makes a decidedly more efficient chimney—being as near as can be perfectly tight, and it does not absorb as much heat as a brick lining.

In topping out a house chimney there is a great difference of opinion as to what is the best mortar; one says one part of lime, and four parts cement, with sand enough to work; another says use only Portland cement throughout the whole chimney. Chimneys of "ye olden times" were laid up in simple lime mortar, and when torn down were found to be very solidly adhering masses; but the fuel used was mostly wood, and while we criticise the mason of to-day for poor lime mortar, we must bear in mind that gases generated by the combustion of coal are the principal destructors of chimneys, decomposing and destroying the life of the mortar which is employed.

and causing soft brick to chip and flake, while the gases from burning wood have scarcely any effect on a well-built chimney.

Use only the best hard brick throughout the chimney entirely; and cement mortar, and be particular to fill the joints full.

The writer has a decided preference for a severely plain chimney top, avoiding all saw-tooth effects, although the top may be drawn out a little all around, say the thickness of a brick length greater in diameter.

On top of the brickwork place a stone coping fastened with dowels of melted lead, and on top, in rainy climates, put a flat, smooth stone, supported at each corner by small blocks of stone; always keeping the opening larger than the size of flue, so as not to smother the draft.

Make the flue inside lining, if of brick, straight and smooth, taking a little extra pains in this direction.

All chimneys should be inspected annually, they should not be permitted to get choked with soot, for two reasons: first, a sooty chimney will not draw well, and it is in constant danger of firing; second, a chimney soot-lined offers special inducements for lightning to strike it.

ILLUS. No. 52.
CHIMNEY STRUCK BY LIGHTNING, JULY 29, 1890.
From *Elec. Zeits.*, Grebel.

CHAPTER X

LIGHTNING PROTECTION

Of an octagonal chimney, 260 feet 9 inches high by 14 feet diameter of flue at Narragansett Electric Lighting Company, Providence, R. I. (*Engineering Record*, 1891, p. 41), the cast-iron cap is encircled with a copper ribbon 1 inch by $\frac{3}{16}$ thick, to which are connected by a rivet and soldered joint, eight brass upright sockets, one in the centre of each panel of the cap.

To these brass sockets castings are secured, by soldered joints, 1¼-inch seamless drawn-copper tubing, which extends upward above the cap and conforms to the shape thereof, and after projecting 5 feet above the upper portion of the cap the tubes are each surmounted by a brass casting 28 inches long, tapering in section and having at its extremity a platinum point 1⅝ inches long.

The encircling ribbon around the cap is connected to the ground ribbon by a brass casting thoroughly riveted and soldered thereto, which, as it runs down the chimney, is secured in position by brass clamps with bolts built into the brick-work as it progressed.

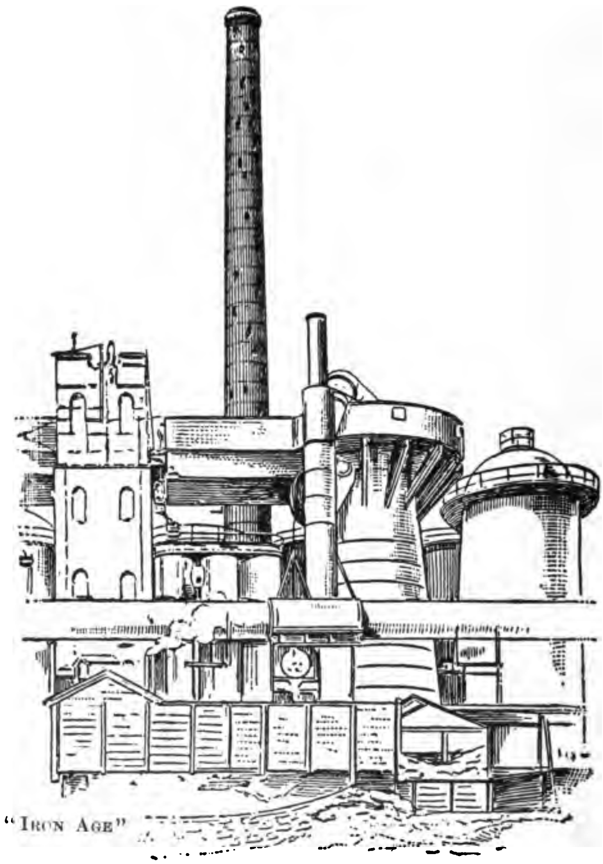
The lower end of the ribbon, which is $\frac{3}{16} \times 1$ inch copper, rolled in one piece, 285 feet long, terminates in a copper plate 30 inches wide by 60 inches long and $\frac{1}{16}$ inch thick, and is buried 4 feet below the natural level of the water in the soil on the premises.

The above plate is buried in a load of powdered coke, 18 inches being placed above, and 18 inches in thickness below the plate, and the whole filled with gravel.

For the protection of brick chimneys, a platinum point or tip is a most excellent one for the top of the rod, but its ex-

pense sometimes prevents its use; but for small chimneys, $50 for such a tip, about 1¼ inch high, is well spent, in fact, it makes a superior tip.

Notwithstanding its extreme hardness, the writer has seen such a point after having been struck, bent over something



ILLUS. No. 53.

like a hook, but back close on itself. Another advantage of this metal is that it always keeps bright.

Steel or iron chimneys are never protected by rods or otherwise, as the metal in the chimney and the bolts running

down deep in the foundation are considered enough protection; the writer does not know of a single steel chimney struck by lightning which produced any bad result, except the one shown by Illustration No. 53, which shows the effect of a stroke on the blast furnace chimney of Friedrich-Wilhelms-Hütte at Muelheim a. d. Ruhr.

The chimney is said to have been perforated in twenty-three places, but strange as it may seem these openings did not materially interfere with the draft of the chimney, as the furnace continued in blast while the repairs were being made. (If natural draft had been in use the draft would have been impaired.)

For lightning protection see also descriptions of other brick chimneys.

The following extracts are made from a paper, "Protection from Lightning," published by the United States Army Weather Bureau.

"Trees near to ditches or water-courses taken by the deluge of water from the higher to the lower ground were more often struck. The same applies to building lightning-rods.

"To prevent the discharge of the fluid the conductor should be surrounded by points, though it often happens that lightning often disregards metallic surfaces altogether.

"*Erection of Rods.*—Few questions have been so thoroughly discussed from practical as well as theoretical stand-points as that of the certainty of the protection offered by properly constructed lightning rods.

"*Use a Good Iron or Copper Conductor.*—If the latter, one weighing about 6 ounces to the foot, and preferably in the form of tape. If iron is used, and it seems to be in every way as efficient as copper, have it in rod or tape form, and weighing about 35 ounces to the foot. 'A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tubular or solid.'"—Sir William Thomson.

"The nature of the locality will determine to a great degree the need of a rod. Places apart but a few miles differ greatly in the relative frequency of flashes.

"The very best ground you can get is, after all, for some flashes but a very poor one; therefore, do not imagine that you can overdo the matter in the making of a good ground. For a great many flashes an ordinary ground suffices, but the small resistance of $\frac{1}{10}$ ohm for an intense oscillatory flash may be dangerous. Bury the earth plates in damp earth or running water.

"'If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallically. The neighborhood of small bore fusible gas-pipes and indoor gas-pipes in general should be avoided.'" (Lodge.)

"The top of the rod should be plated or in some way protected from corrosion and rust.

"Independent grounds are preferable to water and gas mains.

"Clusters of points or groups of two or three along the ridge-rod are recommended.

"Chain or linked conductors are of little use.

"*Area of Protection.*—Very little faith is to be placed in the so-called area of protection. The committee that first gave authority to this belief considered that the area protected by any one rod was one with a radius equal to twice the height of the conductor from the ground. Many lightning-rod manufacturers consider that the rod protects an area of radius equal to the height. The truth is that buildings are struck sometimes within this very area, and we now hold there is no such thing as a definite protected area.

"*Upward Motion of Stroke.*—There is no reason to doubt that the discharge takes place sometimes from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations, say something like 300,000 times per second, the spark or core of incandescent air may seem to have had its beginning at the earth's surface. That is to say, the air-gap breaks down first at a point near the earth.

"*Indifference of Lightning to the Path of Least Resistance.*—Nearly all treatises upon lightning, up to within very recent

times, assumed that lightning always followed the path of least resistance. 'It is simply hopeless to pretend to be able,' says Lodge, 'to make the lightning conductor so much the easier path that all others are out of the question.' The path will depend largely upon the character of the flash.

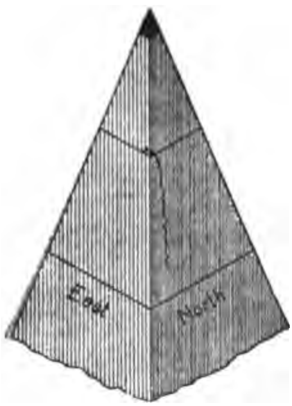
"Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning-rod, well earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices seemingly well protected, have been struck below the rods.

"Paradox of paradoxes, a building may be seriously damaged by lightning *without having been struck at all.* Take the famous Hotel de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunder-storm, some one flash started 'surgings' in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

"Lightning does sometimes strike twice in the same place. Whoever studies the effects of lightning's action, especially severe cases, is almost tempted to remark that there is often but little left for the lightning to strike again. No good reason is known why a place that has once been struck may not be struck again. There are many cases on record supporting the assertion.

"It is not judicious to stand under trees during thunder-storms, in the doorway of barns, close to cattle, or near chimneys and fireplaces. On the other hand, there is not much sense in going to bed or trying to insulate one's self in feather beds. Small articles of steel, also, do not have the power to *attract* lightning, as it is popularly put, or determine the path of discharge.

"*Unnecessary Alarm.*—Just in advance of thunder-storms, whether because of the varying electrical potential of the air, or of the changing conditions of temperature, humidity, and pressure, and failure of the nervous organization to respond quickly, or to whatever cause it may be due, it cannot be denied that there is much suffering from depression, etc., at these times. It is, perhaps, possible that these sufferings may be alleviated. Apart from this, many people suffer greatly from *alarm* during the prevalence of thunder-storms, somewhat unnecessarily, we think. Grant even that the lightning is going to strike close in your vicinity. There are many flashes that are of less intensity than we imagine, discharges that the human body could withstand without permanent serious effects. Voltaire's caustic witticism 'that there are some great lords which it does not do to approach too closely, and lightning is one of these,' needs a little revision in these days of high potential oscillatory currents. Indeed, the other saying, 'Heaven has more thunders to alarm than thunderbolts to punish,' has just so much more point to it, as it is nearer the truth. *One who lives to see the lightning flash* need not concern himself much about the possibility of personal injury from that flash.



ALUMINIUM TIP OF WASHINGTON MONUMENT.

Aluminium tip weighing 100 ounces. Nearly 9 inches high, $5\frac{1}{2}$ inches square at b se. Height from ground, 555 feet (169 metres).

Struck April 5, 1885, without damage. Struck June 5, 1885—Crack on north face just under top stone, extending through the block in a line nearly parallel to northeast corner.

"On June 5, 1885, the Washington Monument, at Washington, D. C., at that time the highest edifice in the world, was struck by lightning, resulting in no damage. On June 5, 1885, it was again struck, leaving a crack; a commission appointed to investigate and recommend additional protection did so with the following results and procedure: Four $\frac{1}{2}$-inch copper rods were fastened by a band to the aluminium terminal and led down the corners to the base

of the pyramidion, and then through the masonry to the columns.

"As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods ½ and ¾ inch in diameter, respectively, furnishing 16 rods in all, connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the 11 highest horizontal joints of the masonry of the pyramidion they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all."

Eight years have now passed since the alterations were made and the monument stands uninjured. Unquestionably, standing as it does, 555 feet high, in the centre of flat, well-watered ground, it constitutes a most dangerous *exposure* for lightning flashes. No better illustration of the value of lightning conductors can be asked.

The octagonal brick chimney of the Heywood Brothers & Wakefield Rattan Company, Wakefield, Mass., was struck by lightning March 5, 1899, the entire exterior shell being knocked away, except the cap which hung from the inner shell.

The chimney was 152 feet high, and inside a 16-foot circle at its base.

See illustration in *Power* of May, 1899.

CHAPTER XI

GENERAL INFORMATION

AIR.

THE air is composed of nitrogen, 78.5 parts; oxygen, 20.6; aqueous vapor, .86, and carbonic acid, 0.4 part. Air contains about 4 grains of moisture per cubic foot.

Air is increased in volume by elevation of temperature. An increased volume of a constant weight of air, of which the initial volume = 1 at 32° Fahr., heated to a given temperature under atmospheric pressure of 14.7 pounds per square inch, may be found by this rule:

$$(65) \quad \text{Increased volume of air} = \frac{\text{Given temperature} + 461}{32 + 461}.$$

If the temperature be taken at 62° Fahr., as in table on page 14, instead of 32°, the divisor is

$$62 + 461 = 523.$$

The weight of atmospheric air is .08072 pound at 32° Fahr.; under the pressure of one atmosphere at 62° Fahr., the weight is .076098.

Absolute zero being 461.2° below Fahr. zero.
Absolute temperature = 461.2 + degrees F.
In the above matter the decimal has been dropped.

SMOKE PREVENTION.

Colonel Dullier, of the Belgian Engineers, has designed an apparatus or device for the absorption of smoke which has been installed at the boiler-house of the South Kensington Museum, London, also at Glasgow, Scotland.

Tests of the latter showed in one case a reduction of the soot in the gases from 73½ grains per 100 cubic feet before treatment to 2 grains after treatment; and in a second case, from 23.3 to 1.5 grains.*

The products of combustion before entering the chimney are taken up one leg of an inverted U-shaped flue, made of galvanized iron, being assisted in their upward course by a steam-jet.

The jet assists in the condensation of the tarry products, and saturates the dust with water vapor. In descending the second leg of the flue the products of combustion are brought in contact with a large number of upward inclined water sprays, which are intended to thoroughly wash the smoke, moistening all particles of dust.

The smoke and water next pass through a chamber containing a helical passage in which they are made to still further commingle, and after all this the gases are allowed to pass into the chimney proper, while the sulphurous wash-water is drained off.

The draft in the flue and chimney, measured with a water-gauge, is said to have shown no diminution after the erection of the apparatus.†

MISCELLANEOUS.

The first mention made of the use of coal as a fuel is in the records of the Abbey of Peterborough, in the year 850 A.D., where is found an entry for twelve cart-loads of "fossil fuel."

To fix bolts in stone-work, Dingler's *Polytechnic Journal* recommends a mixture of 3 parts of sulphur with 1 part Portland cement as superior to either individual constituent.

If cast-iron or bluestone is used for a chimney cap, iron clamps should not be used, according to J. L. Fitzgerald, as they will oxidize and burst the material.

* "Cassiers," December, 1897, p. 182. † Engineering Record, xxix., p. 385.

BUILDING LAWS OF BOSTON, MASS.

Acts of 1892. *That Portion Relating to Chimneys.*

Section 68. No chimney shall be corbelled from a wall more than the thickness of the wall, nor be hung from a wall less than twelve inches thick, nor rest upon wood.

All chimneys shall be built of brick, stone, or other incombustible materials.

Brick chimneys shall have walls at least eight inches thick, unless terra-cotta flue linings are used, in which case four inches of brickwork may be omitted.

Other chimneys shall have walls eight inches thick, and in addition a lining of four inches of brickwork or a terra-cotta flue-lining.

The inside of all chimneys shall have struck joints. No wood furring shall be used against or around any chimneys, but the plastering shall be direct on the masonry or on metal lathing.

All chimneys shall be topped out at least four feet above the highest point of contact with the roof.

No nail shall be driven into the masonry of any chimney.

Section 69. Flues of ranges, boilers, and other similar flues, shall have the outside exposed to the height of the ceiling, or be plastered direct upon the bricks.

Section 70. All hearths shall be supported by trimmer arches of brick or stone; or be of single stones at least six inches thick, built into the chimney and supported by iron beams, one end of which shall be securely built into the masonry of a chimney or adjoining wall, or which shall otherwise rest upon incombustible supports.

The brick jambs of every fireplace, range, or grate opening shall be at least eight inches wide each, and the back of each shall be at least eight inches thick.

All hearths and trimmer arches shall be at least 12 inches longer on either side than the width of such openings, and at least 18 inches wide in front of the chimney breast.

Brick over fireplaces and grate openings shall be supported by proper iron bars, or brick or stone arches.

Section 71. Every chimney in which soft coal or wood is

burned, shall be carried to a height sufficient to protect neighboring buildings from fire or smoke.

Section 72. No smoke-pipe shall project through any external wall or window.

No smoke-pipe shall pass through any wooden partition, without a soapstone ring of the thickness of the partition, with a ventilated air-space of not less than 4 inches around the pipe, nor shall be placed within 8 inches of any wood unless such wood is plastered and protected by a metal shield 2 inches distant from the wood, in which case the smoke-pipe shall not be less than 6 inches from the wood, etc.

TABLE No. 31.

PHYSICAL PROPERTIES OF MATERIALS OF MASONRY, ETC.

All stresses given in pounds per square inch.

Materials.		Ultimate crushing strength.	Transverse strength.	Modulus of elasticity.	Weight per cubic foot.
Brick, flatwise paving	Max.	20,800	3,100	4,000,000	150
	Min..	4,880	1,350	2,000,000	
Paving brick, Philadelphia specifications:					
Red shale		9,090	5,000	....	......
		18,000	6,000	....	......
Yellow fire-clay		8,000	5,800	....	......
		10,000	6,200	....	......
Hard building	Max.	18,400	1,250	4,000,000	125
	Min..	3,800	300	2,000,000	
Soft building		....	....	....	100
Concretes, 1 month old, of following compositions: *					
Cement mortar, 1 of natural cement, 2 of sand		250 to 500	....	....	109
Natural cement mortar and furnace slag		250 to 500	....	....	120
Natural cement mortar and sandstone		250 to 500	....	....	136
Natural cement mortar and limestone		250 to 500	....	....	142
Natural cement mortar and granite		250 to 500	....	....	142
Natural cement mortar and trap		250 to 500	....	....	147
Cement mortar, 1 of Portland cement, 2 of sand		250 to 500	....	....	134
Portland cement mortar and furnace slag		250 to 500	....	....	137
Portland cement mortar and sandstone		250 to 500	....	....	153
Portland cement mortar and limestone		250 to 500	....	....	159
Portland cement mortar and granite		250 to 500	....	....	159
Portland cement mortar and trap		250 to 500	....	....	164
Granite	Max.	24,450	2,700	13,000,000	164
	Min..	12,000	900	1,620,000	
Limestone	Max.	22,800	2,500	8,000,000	158
	Min..	7,000	150	335,000	
Marble	Max.	20,000	2,850	13,550,000	170
	Min..	4,650	150	2,500,000	
Sandstone	Max.	18,750	2,350	2,815,000	139
	Min..	4,100	350	270,000	
Slate		....	....	7,000,000	174
Trap		22,000	....	....	170

* Concretes after six months will be about four times, and at the end of one year will be about six to seven times as strong as at the end of the first month.

—Pencoyd Iron Works, 1898.

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